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TECHNICAL MEMORANDUM

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Portable Rapid Test Fuel Tank Leak Detection System

By

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14. ABSTRACT

The Portable Rapid Test (PRT) tank leak detection system development was conducted under the Chief of Navy's 0817 Pollution Abatement Ashore RDT&E program. Its goal was to bring Navy fuel tanks into regulatory compliance in a cost-effective manner. The PRT Leak Detection System was successfully designed and evaluated for use in 50,000 gallon fuel underground storage tanks (USTs). Using EPA mandated procedures, the PRT achieved a 0.067 gal/hr leak rate with 95% probability of detection (PD) and 5% probability of false alarm (PFA) during 3rd Party Certification Testing at the Barking Sands Pacific Missile Range fuel farm, Kauai, Hawaii . This is the best EPA approved leak rate achieved to date in industry worldwide for a 50,000 gallon in-tank system, with results in 5-hours, and is the only available system which has the dual capability for conducting a combined monthly and annual compliance test. The system allows testing at EPA standard leak rates of 0.10 gal/hr and 0.20 gal/hr with a very high PD and very low PFA. This provides a significant improvement over current methods technologically, operationally, and in short and long-term cost benefits. The final report steps through the development stages of the PRT technology including off-the-shelf component selections, development of new hardware and software, system integration, and laboratory, field and certification testing.

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1.0 INTRODUCTION

1.1 Background

In 1988, EPA issued to states Underground Storage Tank (UST) regulations, for fuel storage, to implement monthly monitoring and annual tightness testing. Monthly monitoring requires that the leak detection system be certified for a leak rate of 0.2 gallons per hour (GPH) and annual tightness testing requires a certified leak rate of 0.1 GPH, both, with a probability of detection of at least 95 percent and a probability of false alarm of no more than 5 percent.

These guidelines also indicate that the leak detection system to be used must be evaluated for performance by an independent third-party following a standard test procedure and submitted to the EPA's National Workgroup for Leak Detection Evaluations (NWGLDE) for review and approval. Once the evaluation is approved, the method is included on a national list of leak detection methods that are ready for use by the states for meeting their leak detection compliance requirements.

The DoD owns and operates hundreds of underground storage tanks that are less than 100K gallons. These tanks, commonly operating at base fuel farms, must comply with EPA, state, and local regulations, and require that either an annual tightness test with monthly inventory reconciliation or monthly monitoring tests be conducted in accordance with published performance standards. Existing technologies either cannot meet performance standards for the large 50K to 100K gallon USTs or do not provide a cost-effective solution.

1.2 Prior Technology

The Portable Rapid Test (PRT) leak detection system developed under this current program is based on prior Navy and industrial partner developed technology called the Low Range Differential Pressure (LRDP) mass-based leak detection system. The LRDP was originally developed for detection of leaks in the world's largest vertically oriented underground storage tanks. The 20 Red Hill tanks, which are owned and operated by the U. S. Navy, are buried over 100 feet deep in the hills above Honolulu, Hawaii and contain 12.5 million gallons of fuel. Each tank is 100 feet in diameter and 250 feet in height. The LRDP technology is briefly described as follows: the in-tank sensor is comprised of (1) a vertical reference tube that spans the full usable height of the tank, (2) a sealed, bottom-mounted container that houses all of the level-measurement sensors, and (3) a special bellows-mounting system that is used to attach the system to the top of the tank. The reference tube is shaped so that it has a cross-sectional area that is proportional to the cross-sectional area of the tank as a function of depth. A valve at the bottom of this tube allows fuel from the tank to enter or leave. When the tank is to be tested for leaks, the valve is closed, thus isolating the fuel in the reference tube from that in the tank. As the level of liquid in the tank fluctuates, the level of liquid in the closed reference tube mimics it—except when the change in level is due to a leak. High precision is achieved because the dynamic range of the differential pressure sensor only

needs to accommodate the differences in level between the reference tube and the tank and not the full height of the tank. The very small differences between the changes in level (pressure) in the tank and those in the tube are detected by a differential pressure sensor that is located in the sealed container at the bottom of the tube. Thus, the differential pressure sensor makes a direct measurement of the change in level that is due to a leak, if one is present. Because the differential pressure is housed at the bottom of the tank, where it is not subject to ambient air conditions, it avoids a common problem of other mass-based leak measurement systems—thermally induced drift of the pressure sensor. In addition, the special bellows-mounting system removes any thermally induced vertical movement of the tank, the manway, or the in-tank sensor. The LRDP system is self-calibrating, and its performance and functionality can easily be checked between tests any time the valve is in the open position.

1.3 Project Objective

This project was conducted under the Chief of Navy's 0817 Pollution Abatement Ashore RDT&E program. Its goal was to bring Navy fuel tanks into regulatory compliance in a cost-effective manner. The PRT system is based upon the Navy's LRDP leak detection system which was developed by the NAVFAC ESC to meet the regulatory need for leak detection for the world's largest UST's, which are owned by the Navy. Upon successful design and extensive evaluation of the systems performance in bulk tanks (greater than 50,000 up to 12.5 million gallons), a decision was made to make a portable system, the PRT, for use in 50,000 gallons tanks and under, based on the need to achieve regulatory compliance, avoid cleanup costs for undetected fuel leaks, and reduce recurring costs associated with monthly monitoring. Developing the PRT from the established LRDP technology presented *significant design challenges* including size limitations (must fit within 8 inch tank opening), low weight and modular configuration (to allow for portability and different tank configurations), fabrication of prototype sliding seal design for quick installation and virtually immediate system stabilization, and redesign/ modification of commercial pressure transducer for direct submersion into fuel, optimum bubble expulsion, operation at intrinsically safe voltage and current, and direct coupling to reference tube without tubing and tubing fittings. The system was also designed to be operated by the tank farm personnel, thus reducing overall costs associated with reliance on outside consultant testing companies.

2.0 TECHNOLOGY DESCRIPTION

2.1 General Description

Figure 1-1 schematic shows the PRT system being inserted into an underground fuel storage tank. The operator is shown lowering a reference tube through a tank access port. The reference tube will rest on the bottom of the tank when fully inserted into the tank. Referring to Figure 1-1 a list of key elements of the PRT system are given as follows:

1. A shaped reference tube with cross-sectional area proportional to the tank area along its depth.
2. A sliding seal attached to the bottom of the reference tube.
3. A differential pressure transducer mounted to the side of the reference tube adjacent to the sliding seal.
4. Electrical conductors that connect the differential pressure transducer to an electronics package outside the fuel tank.
5. The electronics package consists of signal conditioner, terminal block, and Peripheral Component Microchannel Interconnect Architecture Analog to Digital (PCMCIA A/D) card.
6. The conditioned electrical signal is processed by leak detector software on a common laptop computer.

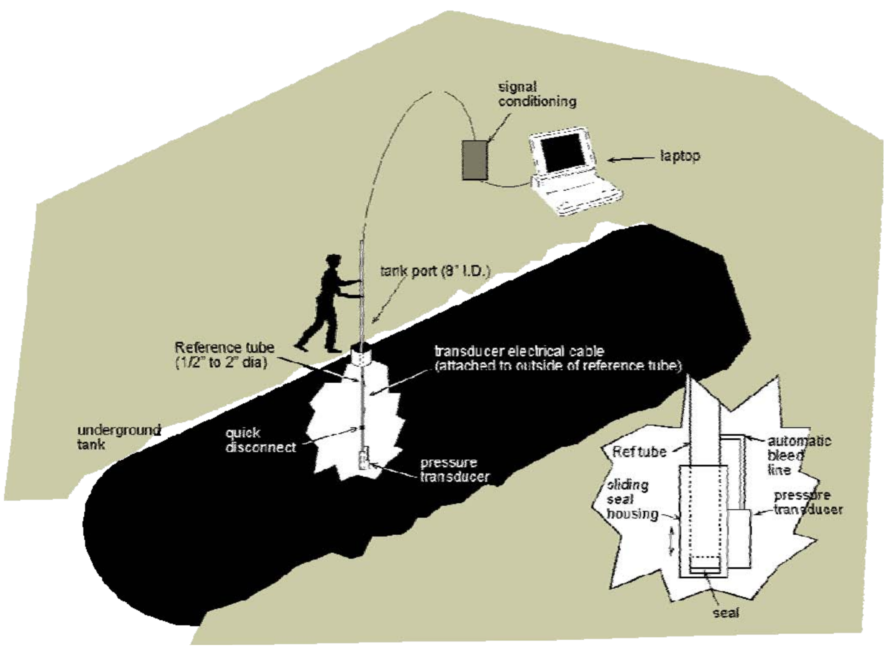


Figure 1-1. RT Leak Detection System Schematic

2.2 System Hardware and Electronics Description

The PRT leak detection system comprises a tank fuel level sensing unit, signal conditioning, and laptop computer. The tank level sensing unit has a vertical reference tube (1) that spans the full height of the tank. This reference tube has a straight or shaped cross-sectional area that matches, with a constant ratio, the cross-sectional shape of the test fuel tank. The bottom section of the reference tube is about 8 to 12 inches and is

detachable from the main upper reference tube. Attached to the bottom section of the reference tube is sliding seal (2) that is spring loaded to be normally open. The sliding seal is designed so that, when resting on the bottom of the test tank, the weight of the reference tube will overcome the sliding seal spring force and the sliding seal will close the bottom of the reference tube so no additional fuel can enter into the reference tube. The sliding seal can be made from a multitude of resilient material configurations including sheet seals, o-rings, ball shaped, etc., and non-resilient material configurations including metal to metal, ceramic to metal, plastic to metal, etc. A differential pressure transducer (3) is attached to the side of the bottom section of the reference tube and is adjacent to the sliding seal. The pressure transducer measures the pressure difference between the height/mass of the fluid in the reference tube and the height/mass of the fluid in the test tank. To minimize fluid cavity areas that can potentially trap or contain vapor bubbles, the pressure transducer is mounted directly to the reference without the use of external tubing. To provide quick thermal stabilization, the pressure transducer body is also of a type that can be directly immersed in the test tank fuel without use of a containment vessel. The bottom section of the reference tube, the sliding seal, and the differential pressure transducer comprises a modular unit that can be attached to any length of upper reference tube so that the modular unit can be adapted to any tank configuration.

The electrical conductors (4) are hermetically sealed to the differential pressure transducer and are contained in a fuel resistant jacket. The conductors/jacket is attached to the outside of the reference tube, runs along the full length of the reference tube, and has approximately 20 to 30feet of additional cable length available for routing to the electronics package (5) outside the test tank. The electronics package consists of a signal conditioner, power supply, terminal block and PCMCIA A/D card. The signal conditioner maintains an intrinsically safe 4 to 20 milliamp (ma) supply current to the differential pressure transducer. The pressure transducer modifies the magnitude of the supply current (i.e., the analog test signal) in relation to actual pressure differentials developed between the reference tube and the test tank. The analog test signal is then output from the signal conditioner as a 1 to 5 Volt signal. This analog signal is then fed to a laptop computer PCMCIA A/D card for analog to digital conversion. Leak detection software (6) installed in the laptop reads the PCMCIA A/D card digital signal and provides signal conversion to pressure change over time or gallon/hr leak rates, input of conversion factors, real time graphing of test leak rate, test start and stop functions, test parameter description notes and real time data saving capabilities. Saved test data can also be easily downloaded into to a spreadsheet (e.g., Excel) for further analysis.

2.3 System Operational Description

The PRT is designed for and recommended for testing tanks containing lower volatile heavier type fuels such as diesel, JP-5, JP-8 etc. All on-site fuel farm operational safety procedures must be consulted and adhered to. The following provides an example sequence for conducting a PRT leak detection test on a large underground storage tank:

1. The operator identifies the underground fuel storage tank to be leak tested.

2. The operator assures that all inlet and outlet valves to the test tank are securely closed.
3. The operator assures that no fuel transfers in or out of the tank are performed during leak testing.
4. The operator should wait a specified time (consult and adhere to all on-site fuel farm safety procedures) after any fuel transfer for static electricity to dissipate in the tank.
5. The operator opens a tank access port of sufficient size to insert the PRT system.
6. The operator lifts and carries the PRT over to the tank access port with the reference tube in the horizontal position. The PRT weighs less than 20 lbs and can be handled by one operator without mechanical assistance.
7. The operator electrically grounds the PRT system to the tank shell.
8. The operator rotates the reference tube to the vertical position in preparation for lowering the PRT system into the tank.
9. Using hand over hand grip movements along the reference tube, the operator slowly lowers the PRT system through the access port into the tank. Since the sliding seal at the bottom of the reference tube is held normally open by spring force, the reference tube will fill with fuel as it is lowered into the tank. This creates a vertical fuel temperature and density profile inside the reference tube very similar to the vertical profile outside the reference (i.e., inside the tank). Similar fuel temperature/density profiles provide quicker system stabilization thereby reducing waiting time before starting leak tests.
10. The operator allows the PRT reference tube to rest on the bottom of the tank and the sliding seal closes under the weight of the reference tube. With the sliding seal closed, the differential pressure gauge now detects the pressure difference between the reference tube side and the tank side. It is this pressure "difference" (i.e., not measuring the full height of the fuel in the tank) that allows the PRT system to accurately detect changes in fuel height in the 0.0001 inch to 0.001 inch range.
11. The operator secures the reference tube to the access port. This can usually be done with a simple elastic cord. Hard mounting of the reference tube is not recommended as tank thermal expansion and contraction may lift the reference tube off the tank bottom and produce large errors in leak detection test results.
12. The operator connects the differential pressure gauge conductor to the signal conditioner. The signal conditioner output is connected to the terminal strip and the terminal strip output is connected to the laptop computer PCMCIA A/D card input.
13. The operator turns on the laptop computer and starts the leak detection software. The operator enters the site-specific test parameters and selects the "Start Test" icon. Leak test final results can be obtained in less than 5 hours.

3.0 PROTOTYPE DEVELOPMENT

Many of the tasks in developing the prototype PRT were conducted simultaneously because of the need to integrate functions, mechanical attributes, and electrical

components of the system. However for ease of discussion, the development effort will be presented here in an approximate chronological order as follows:

1. Concept development of a compact and low weight system
2. Differential pressure gauge selection and development
3. Sliding seal development
4. Interface development of pressure gauge, reference tube, and sliding seal
5. Electronics package development
6. Software development
7. Reference tube design

3.1 Concept development of a compact and low weight system

The PRT in based on LRDP technology that is discussed in the background Section 1.1. The LRDP was designed for permanent installations so problems associated with initial installations—such as purging, weight considerations, etc.—are minor since it only occurs initially. A portable system however, requires ease of installation and rapid stabilization of initial conditions.

The first major change to the LRDP was size and weight. The LRDP pressure transducer, piping, and electronics are encased in a relatively large stainless steel enclosure weighing over 100 lbs. The weight of the case was too much for a portable system and the internal stainless steel piping that routed fuel from the tank and reference tube creates excessive air purging requirements for a system that will be pulled in and out of tanks on potentially a daily basis. The encased system projected diameter was also too large to meet the new design criteria of being able to fit through an 8-inch diameter fuel tank port. After an extensive analysis of adapting an “enclosed” type system to perform as a portable system it was decided that a fundamental change was needed to meet size, weight, and stabilization time design criteria. A new design course was set to do away with the enclosure and expose the pressure transducer directly to the tank and reference tube fuel.

This new design course presented several new technical challenges including:

- Modification of a differential pressure gauge for direct immersion in fuel
- How to port the fuel from the tank and the reference tube to the differential pressure gage and test valve
- How to provide a lightweight and easy method of activating the test valve
- How to configure the system to fit through an 8-inch tank port
- How to purge air bubbles quickly from the system prior to test start
- How to protect the system electronics
- How to provide an intrinsically safe electronics system

Further development efforts were essentially guided by these technical challenges. The following sections discuss the development of individual mechanical and electrical components of the PRT system used to resolve each technical challenge.

3.2 Differential pressure gauge selection and development

The first step was to replace the LRDP Rosemont differential pressure gauge because its size and porting configuration would not allow it to be inserted in an 8-inch tank port. A search was launched for a gauge that would meet numerous design criteria including:

- Low weight
- Small projected diameter for fitting through an 8-inch tank port
- Ability to be directly immersed in fuel
- Very high precision
- Ability to not sustain damage from over pressure
- Rugged design
- Minimal oil canning effect
- Ease of purging air bubbles
- Optimal port configuration for manifold mounting

Over 50 industrial differential pressure gauges were investigated under the above criteria. A gauge that stood out from the field was the Validyne DP-103 gauge. Although the DP-103 gauge met most of the criteria, further efforts were needed to verify operation, integrate the gauge with a newly design manifold, and test the new configuration before final selection of the gauge for the PRT leak detection system.

NAVFAC ESC contracted with Validyne Engineering to conduct a feasibility study followed by a design and development effort to integrate the DP-103 with the PRT system. Appendix A provides details of these efforts. Several key findings came out of these studies. The first was that the gauge in general exceeded precision performance expectations. Another is that the "oil canning" effect—an effect in which a gauge may induce large precision errors when the gauge diaphragm bends positively and negatively across a neutral position—was found to be minimal. One area of concern with the DP-103 gauge, and all other gauges investigated, was the ability to expel bubbles rapidly and completely. To this end, an innovative test was conducted by Validyne to directly observe bubble expulsion under laboratory simulations of field purging methods. For this test, the DP-103 pressure gauge was separated in half and a clear Plexiglas blank was bolted to one of the halves. As shown in Appendix A Phase I Pictures 1 and 2, several novel observations were made from these tests including:

a. the gauge threaded ports tend to trap bubbles
b. the horizontal orientation of the input ports tend to trap bubbles, and
c. the clearance between the gauge body and the Plexiglas—which replicates the actual clearance between the gauge body and the gauge diaphragm—was small enough to trap bubbles, perhaps by capillary or other mechanisms.

From these observations it was fairly straight forward as to the modifications needed for the DP-103 gauge. Validyne proceeded with the gauge modifications of removing the

threaded ports and replacing these with smooth ports sealed with O-rings, reorienting the ports so that the input and output ports sloped upward in the purge flow direction, and increasing clearance between the gauge body and diaphragm. Items a and b above were done in concert with development of the gauge/reference tube interface components discussed in the Section 3.4 Item c, adjustment of the gauge/diaphragm clearance did not create any new system interface problems but there was concern on its affect on the gauge performance. It was later determined through Validyne laboratory testing (Appendix A) that altering the clearance did not impact the gauge performance.

3.3 Sliding seal development

The on/off valve is a critical component of the LRDP and PRT leak detection systems. This valve, when open prior to a test, allows the pressure on the tank side and reference tube side of the differential pressure gauge to equalize. When the valve is closed during a test, it allows the differential pressure gauge to measure very small changes in pressure between the tank and reference tube sides. A drop of pressure on the tank side relative to the reference tube side indicates a leak. However, there are some drawbacks of using a traditional type ball valve (LRDP) for a portable system and these include:

- a ball valve requires either mechanical or electrical activation from outside the tank
- a ball valve must be connected by a piping system that greatly increases the cross-sectional area of the system
- a ball valve piping is prone to trapping bubbles that requires purging procedures
- a ball valve porting area is relatively small and cannot fill reference tube at the same rate it is being lowered into the tank.

Mechanically activating a ball valve from outside the tank presented major problems in keeping the cross-sectional area of the system within the 8-inch projected diameter design goal for lowering through tank ports. The wire and/or rod systems and linkages also were cumbersome for handling by a single operator. Electrically activating the ball valve presented problems with keeping the entire immersed system at intrinsically safe electric power levels. Numerous piping configurations for connecting a ball valve were explored but none satisfied cross-sectional area requirements and all required excessive purging procedures to remove entrapped bubbles.

The solution to the aforementioned problems came through an innovation in the way in which the reference tube was allowed to fill and how the reference tube was isolated from the tank pressure once it was filled. A new sliding seal was developed, shown in Figure 3-1 that essentially allows the bottom of the reference tube to be open as it is lowered into the tank and close under the weight of the reference tube as it contacts the tank bottom. This has several advantages. First, the sliding seal has an inlet area equal to that of the reference tube inner diameter—and over 50 times greater than a ball valve inlet area—allowing the reference tube to fill completely with fuel as it is lowered down. This is believed to help stabilization time prior to test since the reference tube fuel and adjacent tank fuel at each level are of a similar density and temperature. Also, it protects the gauge from repeated over pressurization caused by building up large differential

pressures between the tank side and reference tube side. Second, the sliding seal does not require activation from outside the tank since the reference tube is sealed while the sliding seal rests at the tank bottom. If a re-test is required, the PRT unit is simply lifted off the tank bottom several inches and set back down thus equalizing the pressure between the tank and reference tube. Third, since the sliding seal is built into the reference tube it does not require extra piping to connect which allowed a manifold system to replace all external piping and greatly reduce problems associated with bubble entrapment and purging procedures. The Navy developed sliding seal configuration was one of the primary innovations allowing the PRT patent award.

3.4 Interface development of pressure gauge, reference tube, and sliding seal

Figure 3-1 shows the integrated sliding seal, reference tube, and differential pressure gauge assembly. As shown, a manifold is placed between the pressure transducer and the sliding seal/reference tube assembly. The assembly components are bolted together and the fuel ports are sealed with O-rings at the component interface planes. This manifold configuration replaces all piping for transporting fuel between assembly components and thus removed a primary source of bubble entrapment in the leak detection system. An additional innovation was added to the manifold and connected components to further eliminate bubble entrapment. The system designers, taking advantage of the fact that the direction of fuel flow in filling the reference tube is always the same, provided angled ports to allow buoyancy forces to flush the bubbles out of the manifold/pressure transducer system.

It was the combination of the sliding seal, manifold and selected pressure transducer that allowed the PRT system to meet the cross-sectional design goal for lowering into an 8-inch diameter tank port and still meet stringent leak detection performance goals.

Figure 3-1. PRT Pressure Gauge, Sliding Seal, and Reference Tube Assembly

3.5 Electronics package development

One of the primary technical challenges of using a differential pressure gauge directly immersed in fuel was the design of the in-tank electronics, wiring, and sealing methods. The Validyne DP-103 gauge, designed for extended environmental exposure, required

only slight modifications to seal its internal electronics. However, the more difficult challenge was to seal the electric wires that carry the signal from the DP-103 gauge to the out-of-tank electronics. After numerous design iterations with many types of mechanical interfaces a decision was reached to contract with a company that designs and manufactures sealing systems for deep sea applications. Figure 3-2 shows the construction details of the final submersed water/fuel cable that was used to connect the DP-103 gauge. This cable was connected and sealed to the DP-103 gauge through a polyurethane mold process performed at the manufacturer facility and tested prior to shipment.

It was decided very early in the development stages that all in-tank electronics and power levels must be intrinsically safe—meaning that even in the case of a failed protective enclosure, the electric power levels or energy stored in any electronic device was intrinsically safe for exposure to fuel. Industry standards were followed to maintain intrinsically safe electronics and power levels for all in-tank components. Industry standard electronic barriers were also incorporated at the interface between the in-tank and out-of-tank components (computers, signal conditioners, etc.). Figure 3-2 shows the in-tank and out-of-tank electronic schematic.

Submersed Water/Fuel Cable

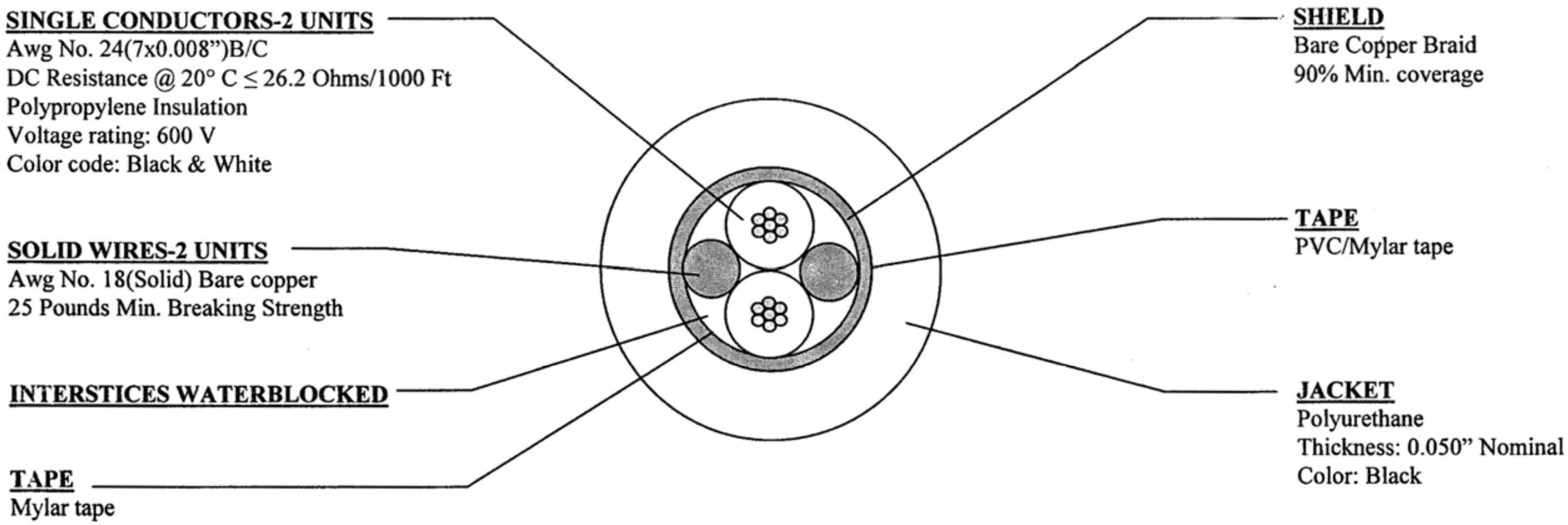


Figure 3-2: Submersed Water/Fuel Cable.

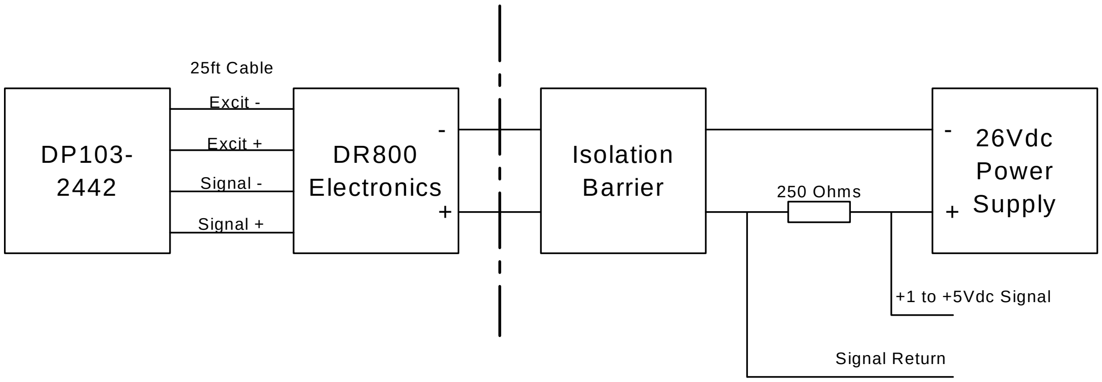


Figure 3-3. In-tank and out-of-tank electronic schematic.

For portability, the out-of-tank electronics including the signal conditioners, power supply, electronic barrier, and interface ports were all configured to fit in a compact and lightweight box. This box is shown in Figure 3-4 on the left side of the laptop with its small computer interface card (on top).

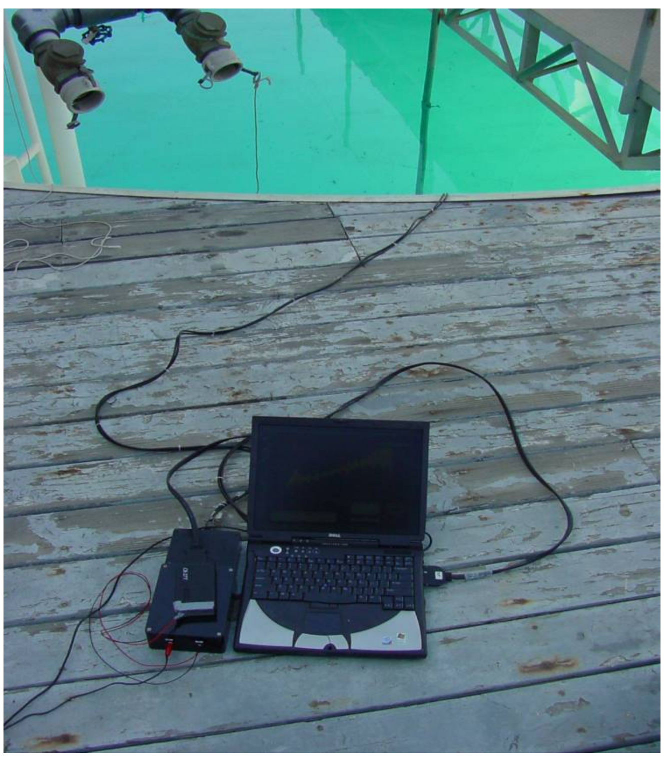


Figure 3-4. Out-of-Tank Electronics Compact Box.

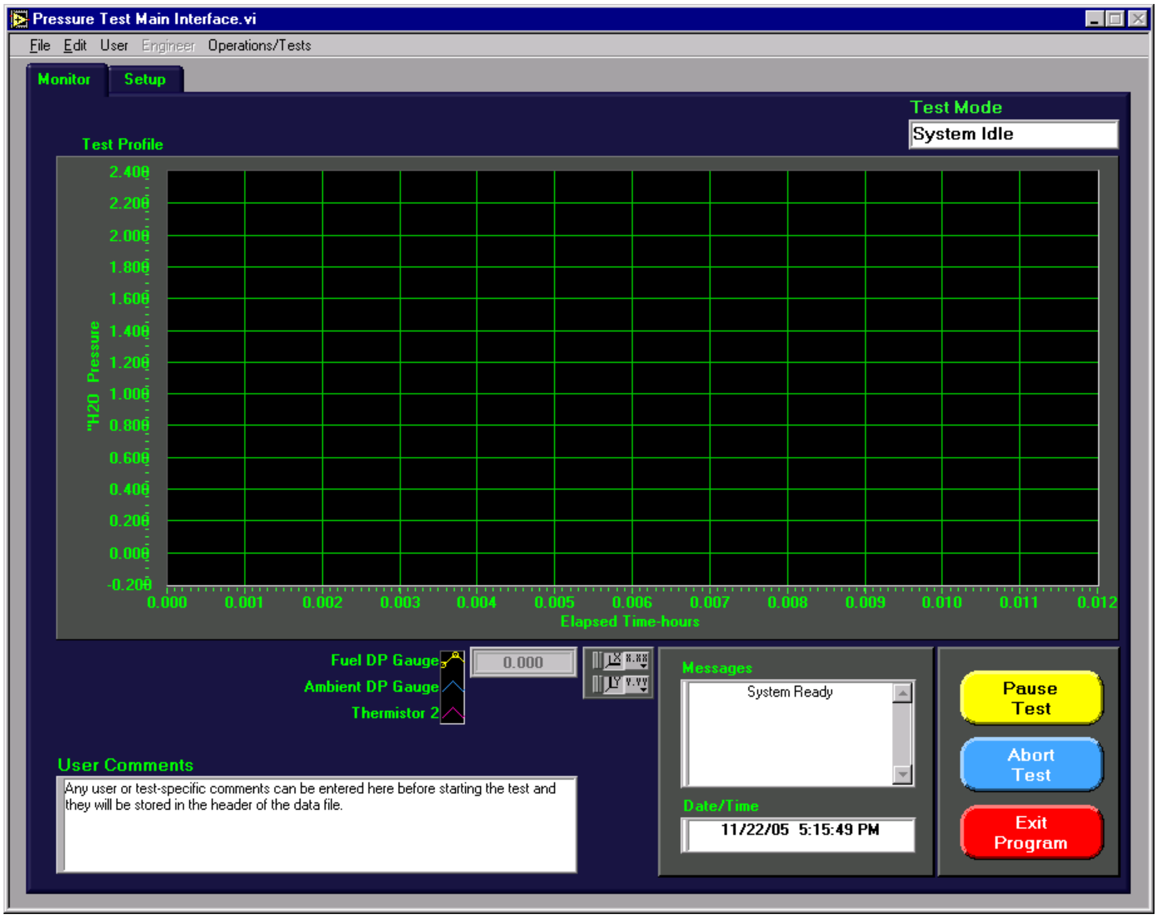


Figure 3-5. Test Monitoring Main Screen.

3.6 Software development

The PRT system collects, converts, stores, plots, and downloads test data using a National Instruments LabVIEW based data acquisition software. The PRT software program code was written by a listed LabVIEW developer based on Navy testing requirements. Figure 3-5 shows the main test monitoring screen selected by the "Monitor" tab. A test is started by selecting "start test" under the Operations/Tests drop-down menu. Once a test is started the software acquires leak detection data from the PRT system and produces live plots allowing the user to monitor the test in real time. The test can be "Paused" or "Aborted" by selecting the appropriate tab. As shown, the units of the horizontal axis "elapsed time – hours" and units of the vertical axis are in "H_20—this translates to pressure in inches of water (1 psi = 27.7 inches of water). This measurements represents the very small pressure difference between the pressure in the reference tube and the tank. If there is no change in differential pressure, this indicates that there is no leak in the tank. If tank pressure is falling relative to the reference tube pressure this potentially indicates a tank leak.

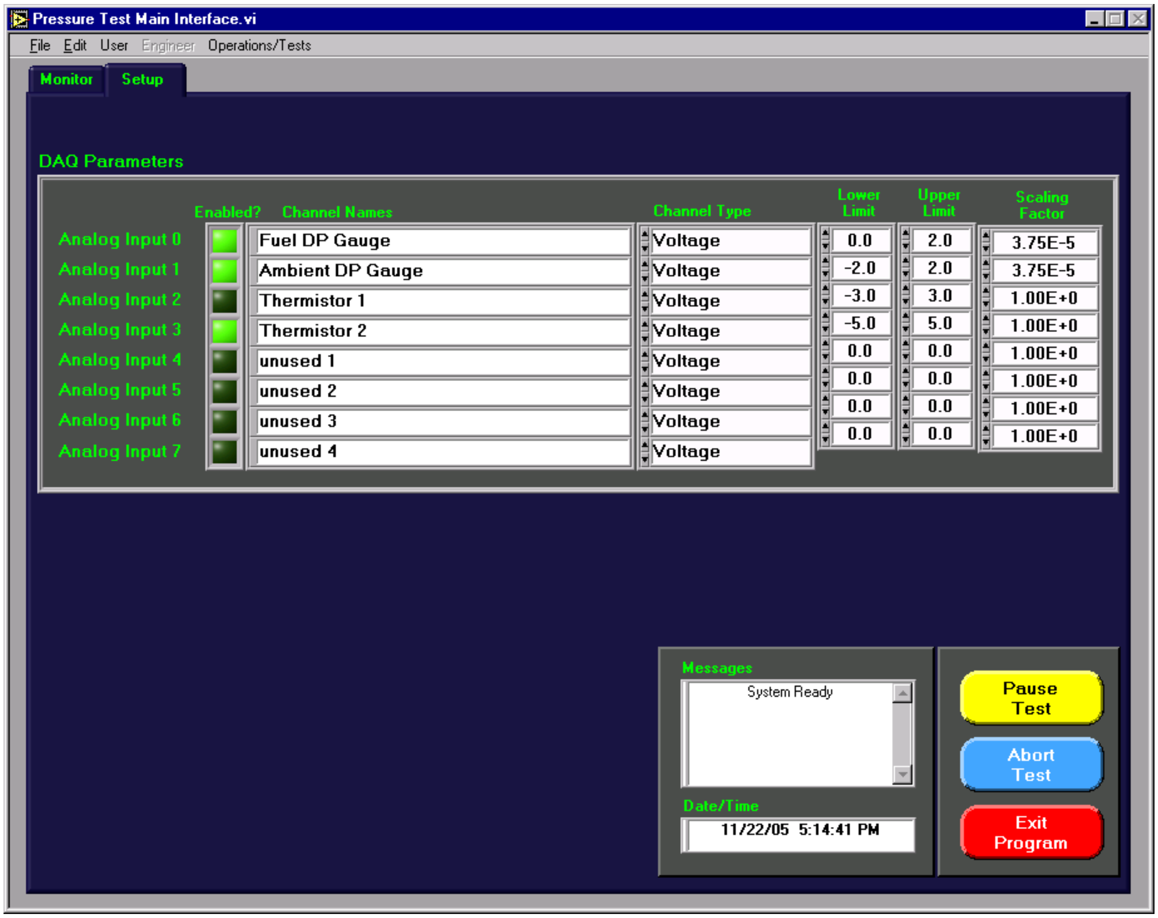


Figure 3-6. Test Setup Screen.

Figure 3-6 shows the test setup screen and is selected by the "Setup" tab. The set-up for a test is very easy in that the user only need to select the "Lower" and "Upper" voltage limits (specified with the PRT hardware) and select the "Scaling Factor" for the test. The scaling factor converts the electrical signal from the differential pressure gauge to the units desired by the user—e.g., psi, inches of water, gallons, liters, etc. The PRT system should be calibrated when used with a new tank and this is done by pulling a known amount of fuel out of tank (for example a liter sample) and observing the change in voltage on the test monitoring screen. Performing the calibration will allow the user to set the scaling factor for whatever units are desired. If the user does not want to specify the scaling factor prior to a test, it can be set at "1" and the test data will be recorded in voltage which can be converted at a later time. Figure 3-6 shows a total of 8 "analog input" channels but only the first channel "Fuel DP Gauge" is needed to run a leak detection test. The other channels were included in the software to allow flexibility during prototype testing.

3.7 Reference tube design

As discussed in the background section, the reference tube is a critical component of the LRDP and hence the PRT system. The reference tube is what allows the differential pressure gauge to measure a very small pressure change between the tank and the

reference tube. The shape of the reference is matched proportionally to the shape of the tank vertical walls to correct for errors of varied thermal expansion of the fuel within the reference tube. No major technological changes in the reference tube design were required in going from the LRDP to the PRT system. However, several mechanical alterations were implemented including: 1) the attachment method at the sliding seal/manifold area, 2) separation of the reference tube into section lengths of less than 7 feet for shipping, and 3) downsizing the reference tube diameter to reduce weight and for ease of handling.

Since the reference tube cross-sectional area must approximate the tank shape, each tank will require a reference tube made for that tank. However, one reference tube can serve multiple tanks at a tank farm for tanks having similar dimension. The reference tube design used for the 3rd Party Test Evaluation at Barking Sands is provided for example in Figure 4-5a and b (see 3rd Certification Test Section). As shown in the figure, Sections 1 thru 3 are designed to be completely immersed in the fuel, Section 4 resides partially in the fuel and partially in the air space above the fuel inside the tank, and Section 5 runs from the tank air space up through the tank vent to the outside.

4.0 DEMONSTRATION TESTING

4.1 Laboratory Testing

The Validyne DP-103 differential pressure gauge and sliding seal assembly were tested extensively in the laboratory prior to field testing. These tests were primarily concerned with long term drift of the sensor and the effect of diurnal temperature changes on the gauge. Figure 4-1 is provided for example. The graph line in Figure 4-1 represents the electrical output of the Validyne DP-103 gauge over a period of 115 hours. This particular tests represents only the noise and drift of gauge itself since the reference tube is open and pressure cannot build up between the laboratory tank and the prototype reference tube. The vertical axis represents Volts and the horizontal axis represents test hours. To make this graph more meaningful related to field testing in 50K gallon tanks several conversions must be performed as follows:

1. The DP-103 gauge was calibrated for this particular laboratory set-up by pulling eye dropper amounts of fuel out of the test tank. The resulting pressure drop per mV was calibrated as follows:

Cal = **.0000375 "H_2O/mV**

2. In Figure 4-1, the worst case change was 10mV over a 19 hour period. This essentially represents the drift of the sensor over that 19 hour period.

Therefore,

Worst case change = 10mV/19hrs = .52 mV/hr x .0000375"H2O/mV = **.0000195 "H_2O/hr**

3. Now, that rate of sensor drift can be converted to a hypothetical inflow/outflow of gallons of fuel in a 50K gallon tank:

Gallons per hour error in a 50K 12 feet diameter tank = (.0000195 in/hr)(441 gal/in) = **.0086 gal/hr**

When compared to tank leak detection rate goals of **0.100 gal/hr**, it can be seen that this sensor drift (.0086 gal/hr) would have very little impact when testing 50K gallon tanks.

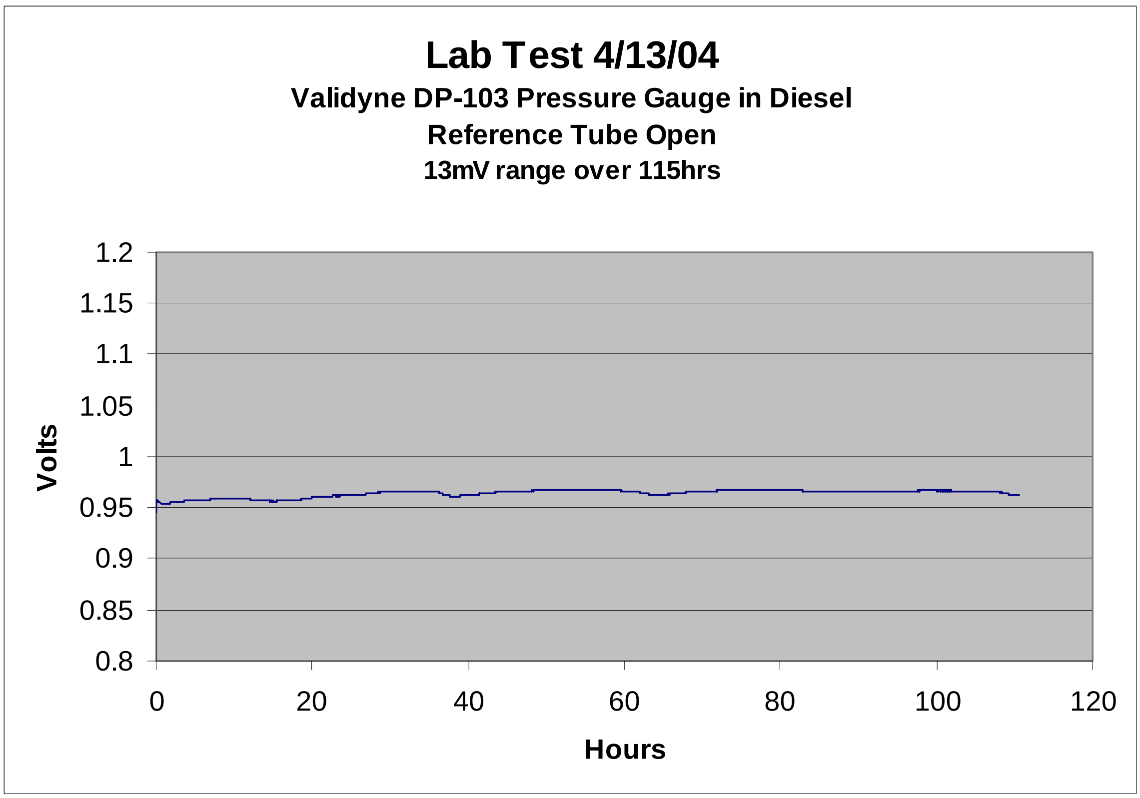


Figure 4-1. Laboratory Testing of Validyne DP-103 Differential Pressure Gauge

4.2 Dive Tank Testing

After the successful completion of the laboratory tests a full scale prototype of the PRT system was assembled for testing at the NAVFAC ESC dive tank. Whereas the laboratory tests were intended to test the accuracy and precision of the PRT sensor and electronics, the dive tank test is designed to test the functionality of the system as a

whole. Precision testing in the dive tank is not possible due to the overriding effects of diurnal tank expansion/contraction of the above ground tank.

Figure 4-2 shows a tester lowering the reference tube into the dive tank. The assembly at the bottom of the reference tube contains the differential pressure gauge, manifold, sliding seal and the "cast on" wiring harness. As can be seen the unit is very portable and can easily be handle by a single person. As the tester lowers the assembly into the tank, the reference tube freely fills with fluid.

Figure 4-3, shows the sliding seal closing as it contacts the tank bottom as the reference tube is lowered its few inches. When the sliding seal fully closes, the reference tube is filled to the same level as the tank. The reference tube side of the differential pressure gauge is now isolated from the tank side of the reference tube and the gauge reads essentially zero differential since the tank and reference tube water heights are equal. At this point, any loss of fuel in the tank would lower the pressure on the tank side of the pressure gauge relative to the reference tube side and would register as a leak in the PRT system.

For the most part, the dive tank tests of the PRT system were successful. However, it was observed that there was some inconsistency with the sliding seal mechanism. Although the sliding seal worked properly the majority of times, there were occasions the mechanism did not seat properly and leaks could occur between the tank and reference tube. A leak of this nature will constantly allow the reference tube and the tank to equalize in pressure. When running leak detection tests this would be highly undesirable because it could produce false negatives. Another problem with this version of the prototype sliding seal was that it was difficult to manufacture—requiring very precise alignment of the bushing rod guides attached to the reference tube.

To solve these problems, the sliding seal mechanism was redesigned to be manufactured completely as a machined part instead of assembled onto an existing tube and the use of an O-ring type assembly was incorporated to achieve a 100 percent effective seal.

Figure 4-2. PRT System is Shown Here in Pre-Evaluation Dive Tank Test.

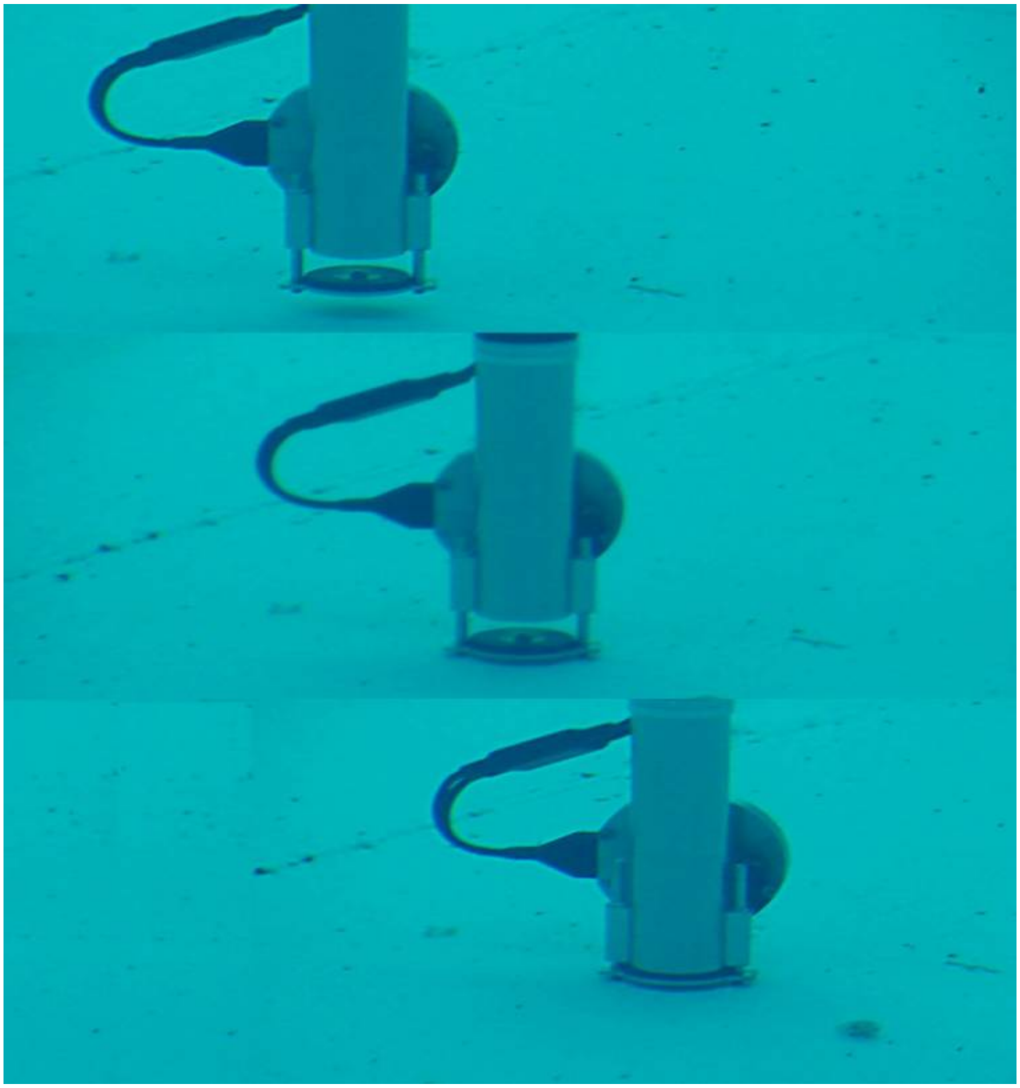


Figure 4-3. PRT Sliding Seal Shown Closing upon Contact With Tank Bottom.

4.3 3rd Party Certification Tests

The 3rd Party Certification Tests were conducted at the Barking Sands Pacific Missile Range, Kauai, Hawaii. The full 3rd Party Certification Test Report is provided in Appendix B. The test tank was a nominal 50,000-gallon cylindrical bulk underground storage tank containing Jet A fuel that was 59 feet long and 12 feet in diameter. The tests were conducted during November and December of 2004.

The 3rd Party Test leak simulations, data collection, data analysis, and reporting were conducted by Ken Wilcox Associates (KWA), Inc. The leak simulation procedures used in the evaluation were those described in the bulk tank protocol, which are also identical to those described in the standard EPA protocols for Automatic Tank Gauge (ATG) and volumetric systems. Leak simulations were conducted by removing fuel from the stilling well of the tank at a steady rate using a peristaltic pump. The induced leak rate was

calibrated volumetrically at the beginning of the test and the total volume removed from the tank was used to calculate the induced leak rate. Testing at each leak rate continued for approximately 24 hours and was assumed to be constant during this time period. The volume of fuel removed was measured gravimetrically using a balance with a resolution of 2 grams. This mass was then converted to volume using the density of the fuel in the tank. The density was determined by weighing a known volume (2 liters) of fuel.

Openings in the tank were available for the PRT system equipment and for the KWA leak simulation equipment. The test tank was made available to KWA staff 24 hours a day for the duration of the evaluation. Fuel was transferred into and out of the tank using the fuel farm pumping systems. The tank was filled to a nominal level of 95 percent for all of the 12 tests that were conducted. The level was reduced to 50 percent and refilled again to 95 percent between each pair of tests. No induced temperature changes were provided for these tests, but some small differences in temperature were observed during the testing.

Figure 4-4 shows the PRT system outside the test tank (between the white tank vent and the ladder) while the tank was being emptied to 50 percent and refilled. The differential pressure gauge, sliding seal, and manifold assembly is shown attached to the bottom of the reference tube. Since the Barking Sand test tank is a horizontally oriented cylindrical tank, the tank side walls are curved. Like the LRDP technology, the PRT technology requires that the reference tube be shaped to proportionally match the shape of the tank. This ensures low errors due to thermal expansion of the fuel. Figure 4-5a and b depict this shaped reference tube design for the Barking Sands test tank. As shown, the reference tube was manufactured in sections for ease of air shipment and ground transport. The sections were assembled at the test site location.

Figure 4-4. PRT System Shown Next to Barking Sands, Kauai Test Tank.

Material
1. 1.152" ID, 1.25" OD SST 304 tubing. MMC 8989K428
2. 1.652" ID, 1.75" OD SST 304 tubing. MMC 8989K368
3. 1.902" ID, 2.0" OD SST 304 tubing. MMC 8989K408
4. Custom Section
5. 1.402" ID, 1.5"OD SST 304 tubing. MMC 8989K348

Notes:
1. Cut vents in tubing 2" long by ½" wide with center of vent located 6 inches from top of custom piece. 3 places equally spaced around.
2. Length Dimensions ± 1/32"
3. PRT unit: 0-1 inch is solid. 1 – 8 inches is 1.05 inch ID, 1.25 inch OD
4. Top of tank is located 12" above the top of the custom piece.
5. Measurement area limited to the 24" custom section, between 9' and 11' depth of the tank.

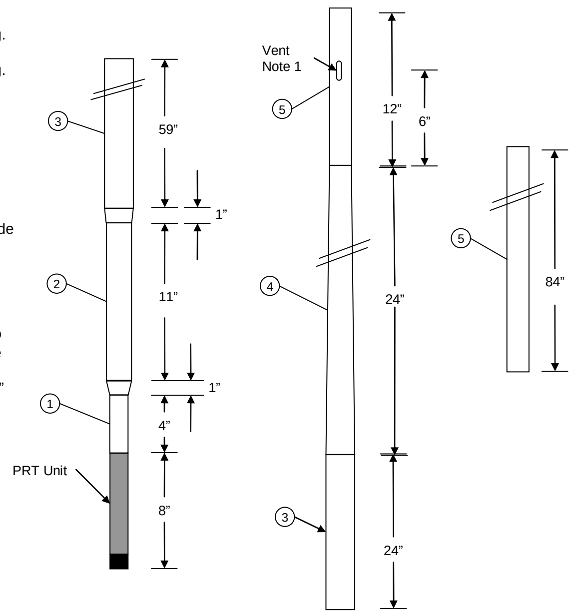


Figure 4-5 (a). Barking Sands Test Shaped Reference Tube Bottom and Middle Section.

Height (in)	Inner Diameter (in)
24	1.530
23	1.542
22	1.553
21	1.565
20	1.577
19	1.589
18	1.601
17	1.613
16	1.625
15	1.637
14	1.649
13	1.661
12	1.672
11	1.684
10	1.696
9	1.708
8	1.721
7	1.732
6	1.744
5	1.756
4	1.768
3	1.780
2	1.791
1	1.803
0	1.815

Piece 5
4 inches, from 1.577 to 1.530 ID

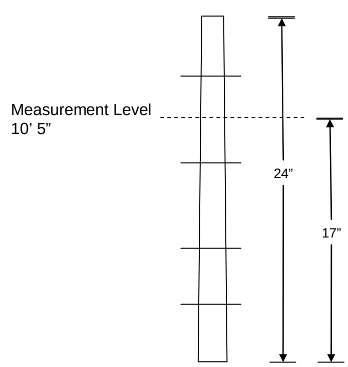
Piece 4
6 inches, from 1.649 to 1.577 ID

Piece 3
6 inches, from 1.721 to 1.649 ID

Piece 2
4 inches, from 1.768 to 1.721 ID

Piece 1
4 inches, from 1.815 to 1.768 ID

Notes:
- ID tolerance of +/- 0.05 inches.
- Wall thickness of 0.050



b. Barking Sands Test Shaped Reference Tube Top Section.

The following test procedure was used throughout the 3rd Party tests:

1. KWA induced an unknown leak prior to the tank being completely refilled.
2. Approximately 30 minutes after the tank was filled back to its operational level, the PRT system was lowered into the tank. The PRT operator would climb the ladder shown in Figure 4-4, move the PRT in position over the tank port, and lower the PRT to the tank bottom. A simple elastic cord was attached from the PRT upper reference tube to the tank port to assure the PRT sliding seal remains in good contact with the tank bottom.
3. The PRT operator would then select "start test" on the system laptop to activate the data recording/analysis/plotting functions of the PRT system.
4. After an approximate 24 hour period the PRT system test would be stopped. KWA testers would stop the unknown induced leak after confirming the PRT system test was concluded.

Analysis of the PRT test data was very straightforward. A function of the PRT software allows a direct download into Excel or other spreadsheet programs. The raw test data, in units of mV vs. hours, was downloaded and plotted in Excel and simple linear regression fit of the plot was performed. An example Excel plot (3rd Party Test #2) is shown in Figure 4-6 depicting the actual leak rate plot and the overlaid best fit linear regression line. The slope of the linear regression line represents the leak rate. In this graph, an upward slope represents a tank leak since the differential pressure gauge is outputting the reference tube pressure minus tank pressure—as the fuel is pulled out of the tank, the reference tube pressure is increasingly higher than the tank pressure resulting in the upward graph slope in Figure 4-6.

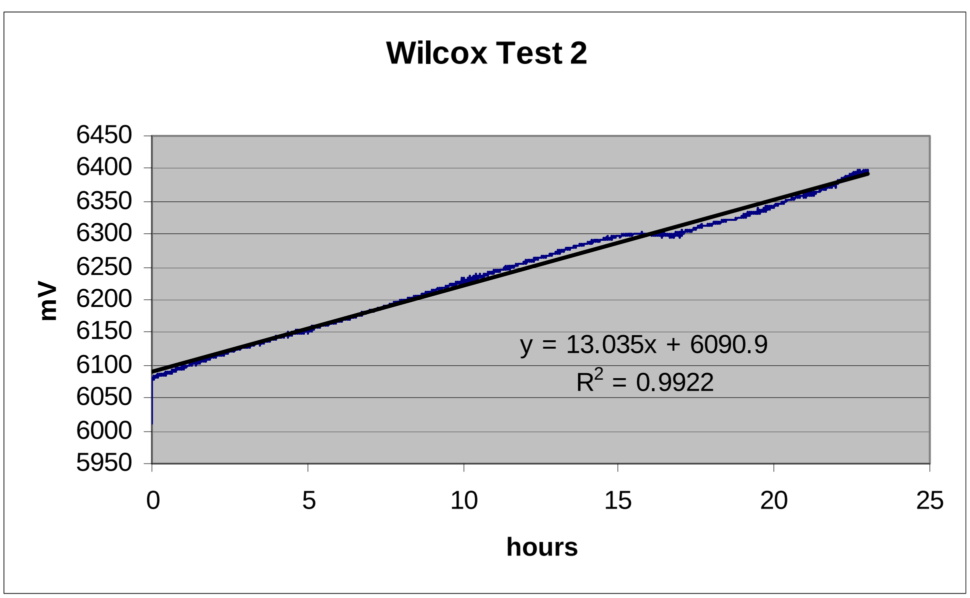


Figure 4-6. Third Party Certification Test #2 Data.

To convert the linear regression line units of mV/hr into gal/hr of fuel, a calibration must be performed. This is accomplished by taking a small amount of fuel out the tank over a short period of time. A standard liter sampler on hand at the fuel farm was used to pull out the calibration fuel samples. Figure 4-7 shows the large displacements recorded by the PRT system when these relatively small samples are pulled out of a 50,000 gallon fuel tank. This type of calibration data is then used to convert the mV/hr leak detection data to gal/hr.

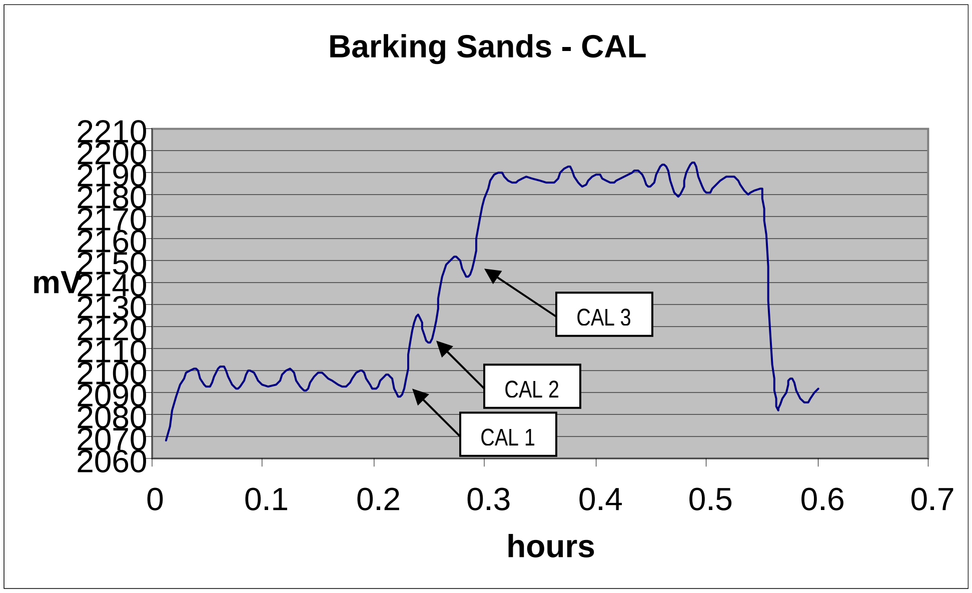


Figure 4-7. Calibration Samples Pulled from Tank.

After the 12 certification tests were complete, the Navy testing team submitted the PRT system estimated leak rates for each test to KWA. A 5-hr test period from 0300 to 0800 was selected for the calculation of each leak rate submitted—tank farm fuel transfer activity was usually lowest during these hours and therefore best for leak testing. The leak rate reported by the PRT system was compared by KWA to the actual blind induced leak rates. KWA used standard statistical methods and EPA protocols to calculate the key leak rate Parameters of Minimum Detectable Leak Rate (MDLR), Probability of Detection (P_D), and Probability of False Alarm (P_{FA}). The statistical analysis methods and parameter definitions are discussed in detail in Appendix B.

Table 4-1 provides a summary of the key parameters calculated for the PRT 3rd Party Certification Tests. The three variables P_D, P_{FA}, and Threshold (C) are related and in accordance with EPA protocols can be varied within the range of a P_D of at least 95 percent and a P_{FA} of less than 5 percent. Table 4-1 illustrates some of the possible combinations that might be useful in a commercial implementation of the PRT system. For example, if a customer wanted a very low probability of false alarms when detecting leak in tanks, they might chose Method "c max" with a P_{FA} of only 0.1 percent and the minimum P_D of 95 percent. However, if the customer desired very high probability of

detection of a leak and could tolerate a slightly higher probability of false alarms, then they might choose the "c min" method.

Table 4-1. Summary of the P_D and P_{FA} Results – PRT 5 Hour Test

Method	Leak Rate (gal/h)	Threshold (gal/h)	P_D (%)	P_{FA} (%)
c	**0.10**	**-0.045**	**99.1**	**0.8**
c min	0.10	**-0.063**	**99.8**	**4.9**
c max	0.10	**-0.026**	**95.0**	**0.1**

The minimum leak rate and associated values for P_D, P_{FA}, and threshold obtained for the PRT 3rd Party Certification Tests are the best achieved by industry to date for an in-tank system for bulk tanks of less than 75,000 gallons. The main advantage of this achievement is that the PRT may be used to test at the 0.10 gal/hr leak rate (common annual tightness requirement) while having a high probability of detection and low probability of false alarm.

5.0 TECHNOLOGY COST AND IMPLEMENTATION

5.1 Technology Cost

The PRT has several significant cost advantages over other internal, and external-based technologies. The cost advantages are realized because of the very high performance of the system and the low probability of false alarm, the on-line monitoring capability of the system if permanently installed in a tank, the capability of the system to conduct a short test (5 hours), the ability to use in a portable mode to test multiple tanks in a tank farm, and the low recurring costs associated with testing. It is estimated that the savings of the PRT compared to other in-tank systems would result in a payback of less than one year. The costs of other in-tank methods are higher because of lower performance and the inability to meet both the monthly monitoring and annual precision regulatory requirements with a single on-line system. The payback period is further reduced when compared to the common tracer method of tank testing. The cost of a tracer method is expensive because of the high recurring cost of testing and laboratory analyses, approximately \$36,000/yr vs. \$2,400/yr for the PRT. The tracer test method also requires initial installation of monitoring wells surrounding the fuel tank. The capital costs and operational costs of PRT are fairly small in comparison. Table 5-1 provides an approximate cost breakdown of the PRT hardware and electronic components. The reference tube cost is not included in this breakdown because it must be designed and fabricated for the specific tank or multiple tanks in a tank farm that the PRT system is to be monitoring. Nevertheless, the total PRT hardware cost of \$9,000 is very competitive compared to other tank monitoring systems while having all the aforementioned advantages of a high performance on-line in-tank system.

Table 5-1. PRT Hardware And Electronic Component Cost Breakdown

PRT Component	Cost ($)
Validyne DP-103 submergible differential pressure gauge	2,500
Polyurethane cast wire harness	2,500
Sliding seal and manifold	1,200
Reference tube	TBD
Validyne DR800 electronics, isolation barrier, power supply, and box with in/out cable jacks	1,500
Computer Interface Card	1,000
Misc cables	300
TOTAL	**$9,000**

5.2 Technology Implementation

The PRT technology was awarded two U.S. patents on December 5, 2006. The primary patentable feature of the PRT system was the sliding seal coupled to the differential pressure gauge. Prior to the PRT system there had been no such sliding seal configuration used in any government or commercial tank leak detection system. In 2008, the technology and rights of use of the patent was licensed to an industrial partner to implement the technology throughout the DoD and commercial markets.

Further implementation efforts of the technology are ongoing through the Information and Technology Transfer Branch code EV423 at NAVFAC ESC. EV423 awarded and continues to monitor the industry licensing efforts and has issued technology publications including the Fact Sheet “Portable Rapid Test (PRT) Leak Detection System” and the Pocket Card “Portable Rapid Test (PRT) Leak Detection System”.

APPENDIX A

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March 1, 2002

Fuel Tank Leak Detection System
Phase One Report

Task Description - Phase One of the Fuel Tank Leak Detection System Program: Validyne will work closely with the Navy at Port Hueneme to finalize the technical requirements of the system. Also included will be a conceptual design of the proposed solution along with drawings and a performance specification summary. Phase One is intended to include study of the problem to ascertain which Validyne transducer and electronic package is most suitable for the task, and preliminary tests to indicate that the selected transducer and electronic package will provide the desired data to accomplish the desired result. Delivered, as part of this task will be drawings, performance specifications, and preliminary findings, including test results of the proposed sensor/electronics solution.

Requirements

Pressure range - Full scale range shall be ±0.1 inches of H_2O
Fluid compatibility – Submersed components shall be resistant to JP5, JP8 or Diesel type fuels
Output – Shall have a 0 to 5 volts DC output from electronics to DAS system
Resolution – Shall be .0001 inches of H_2O (represents about 0.4 gallon in a tank 27 meters in diameter)
Intrinsic safety – Shall meet FM certified hazardous conditions
Plumbing and Mechanical configuration – Shall interface to the portable system insertion apparatus (see figure 2)
Size constraints – Shall be of a size that can fit thru a tank access hole of 8 inch dia. max.

Proposed Solution:

Validyne proposes to provide a modified Validyne model DP103 transducer (see figure 1) with a Validyne model P432 carrier demodulator based on the requirements outlined in the requirements section of this report and tests performed on the DP103 transducer. All plumbing and other components of the system are to be provided by others. The electronics package has been selected because it has already been FM approved. Table 1 defines the standard DP103 specifications.

The following are the modifications that will be made to the standard DP103 transducer to meet the necessary requirements:

1. Special mounting features for mounting on customer's plumbing.
2. Elimination of threaded ports.
3. Incorporation of large smooth through ports.
4. Elimination of small vent port and replacement with large vent port.
5. Placement of a fill and vent along vertical axis.
6. Placement of a fill and bleed port so that all bubbles will be expelled.
7. The gap between the diaphragm and transducer body will be increased to eliminate surface tension problems
8. Replacement of threaded ports with "O" ring seals
9. Use of "O" rings which are compatible with tank fluid

Accuracy*:	±0.25% Full Scale
Hysteresis:	0.1% pressure excursion
Overpressure:	±200% Full Scale with less than 0.5% Full Scale Zero Shift
Overpressure Limit:	15 psi for -26 and below
Line Pressure:	100 psig, less than 1% Zero Shift
Inductance:	20mH nominal, each coil
Zero Balance:	≤ ±5mV/V at rated excitation
Excitation:	
Rated:	5 Vrms at 5kHz
Limits:	30 vrms at 3kHz 1 to 20 kHz with 20 mh coils
Sensitivity:	20mV/V for Full Scale, nominal
Pressure Media:	Corrosive fluids, compatible with 410ss, Inconel, and Buna N O-Rings.**
Temperature:	
Operating:	-65 to 250°F
Specified	0 to 160°F
Thermal Zero Shift:	1%FS/100°F typical
Thermal Sensitivity Shift:	5%/100°F typical
Pressure Cavity Volume:	35X10 $^{-3}$ cubic inch (.57 cc)
Volumetric Displacement:	3.X10 $^{-3}$ cubic inch (.057 cc)
Pressure Connection:	1/8-27 NPTF
Electrical Connection:	TBD
Size:	1.25" X 4" X 4.375"
Weight:	39 ounces (1.11 Kg)

Table 1 – DP103 Specifications

Tests Performed

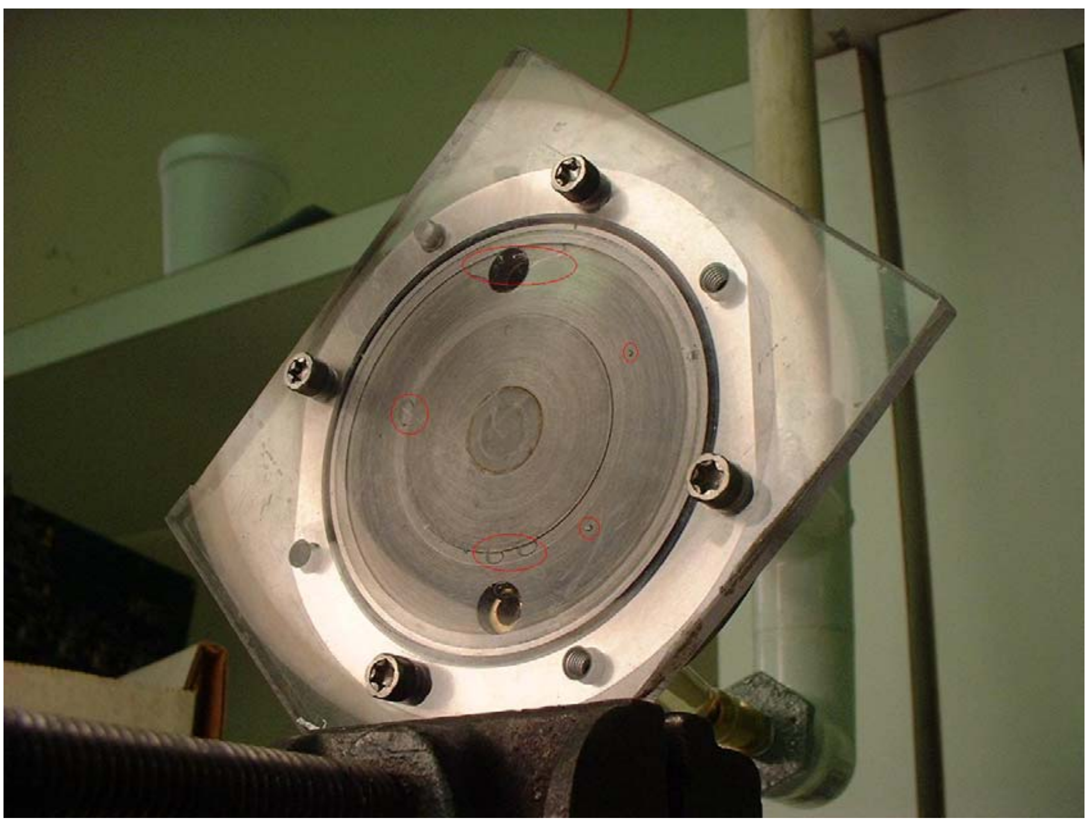
Fill Test

A clear plexiglass sheet was fabricated to replace the diaphragm of a DP103 sensor. The 0.25" thick clear plastic was bolted against half of the DP103 body. This arrangement

allows close observation of how the transducer fills with liquid. The DP103 “half sensor” was oriented such that the vent port was the highest point. This allows venting of any air bubbles. The lower port would simulate the port where liquid will first enter the sensor cavity. The upper port will simulate the port where air will escape. For this experiment these two ports were plumbed to a vertical tube. This vertical tube had a diameter of 0.5 inches. The transition plumbing from the sensor ports to the vertical tube was clear Tygon tube. Liquid was poured into the vertical tube. This liquid first entered the sensor cavity from the lower port until the tube filled up to the level of the upper port. By that time all the air that was able to escape through the upper vent port had escaped. Below three experiments show different results of the three different designs and/or change of fluid.

Test 1

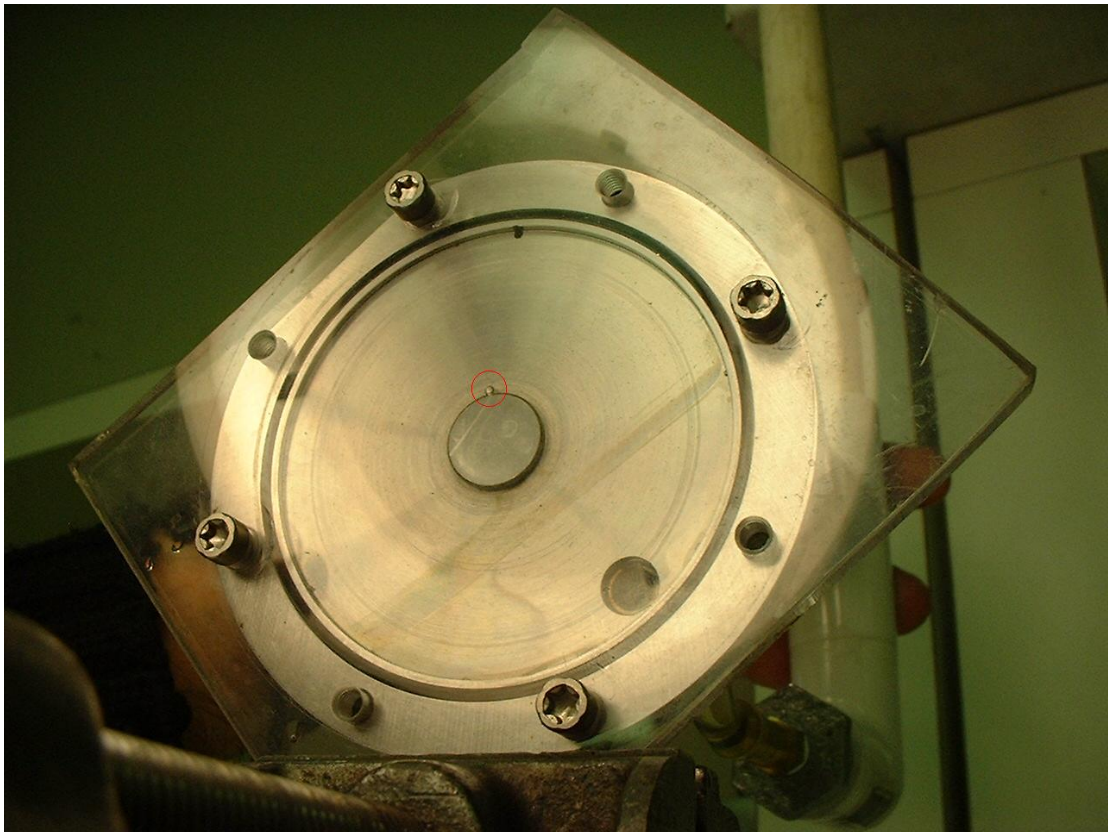
Sensor: Standard DP103
Media: Water
Result: Bubbles formed (encircled in red) in various locations as shown in Picture 1



Picture 1

Test 2

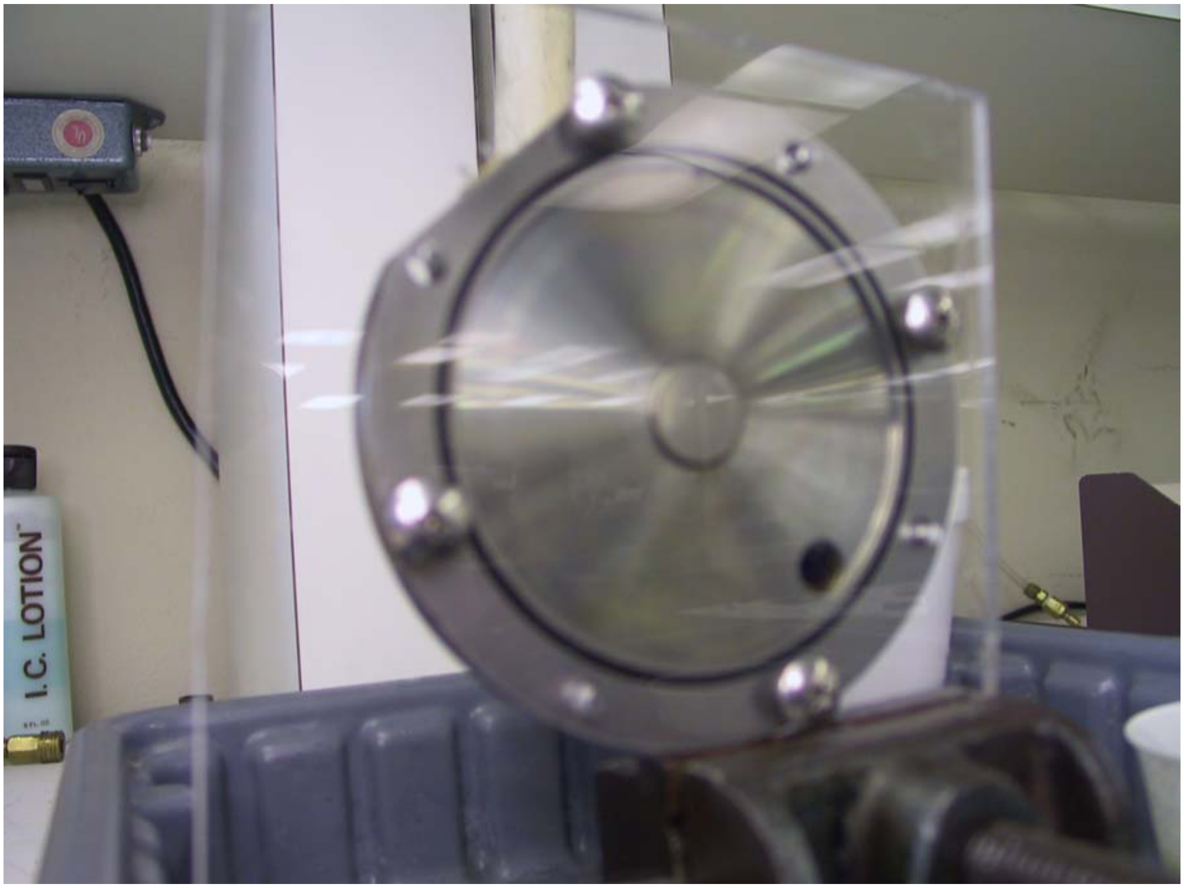
Sensor: DP103 modified with a larger gap. Surfaces are polished. Lid is tig welded.
Media: Water
Result: Bubbles (encircled in red) only at threaded port and at top of the center as shown in Picture 2



Picture 2

Test 3

Sensor: Same sensor as used in test 2.
Media: Diesel fuel
Result: Bubbles only at threaded port



Picture 3

In summary it was found that the DP103 with increased cavity size allowed air to escape and eliminated the formation of bubbles. Using fuel as liquid in test 3 showed that bubbles where not created during the filling process.

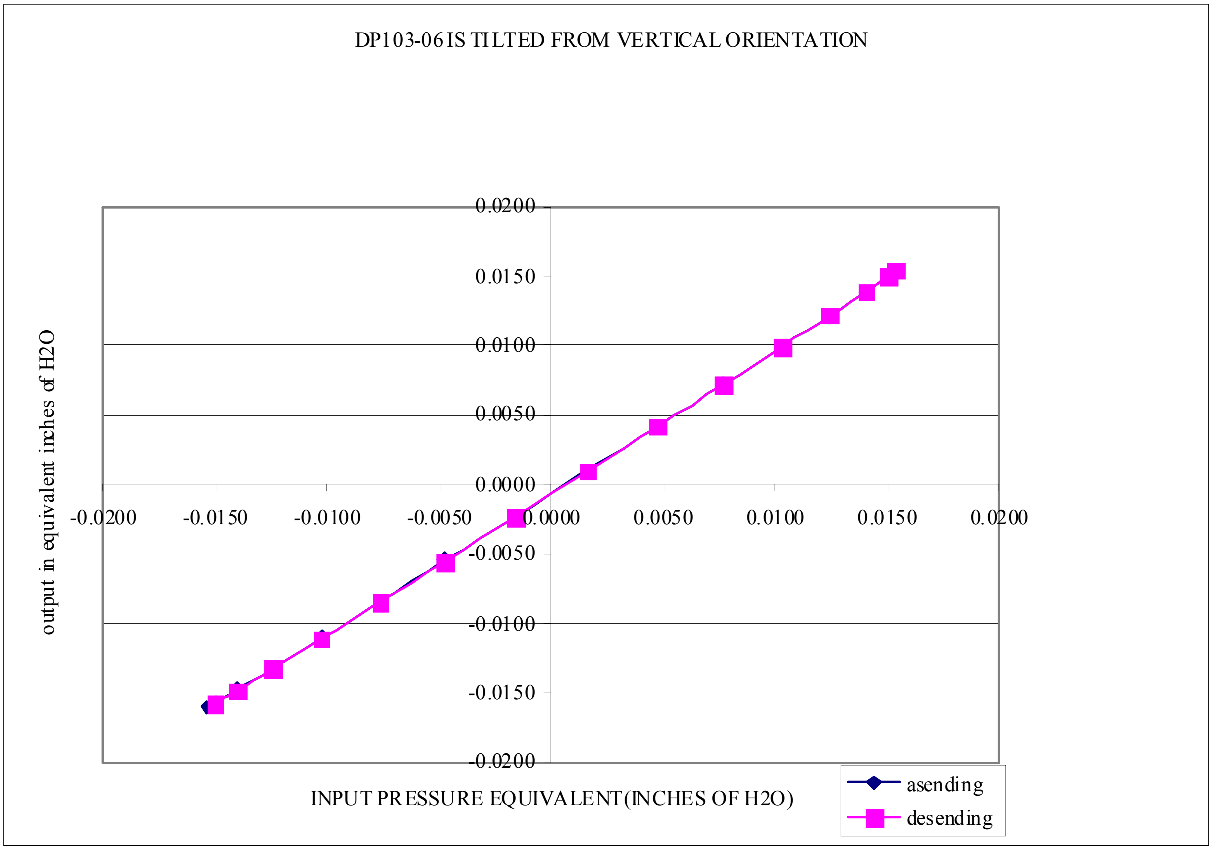
Pressure test

This test was intended to demonstrate that the selected transducer is not subject to "oil canning" around the zero pressure point, and that the required resolution can be realized. A resolution about five times better than that required was demonstrated. A DP103 transducer was mounted to a rotation table. This table allowed rotation of the sensor from horizontal to vertical position. This movement was very gradual and to a precise angle. The starting position of the sensor was with the diaphragm horizontal and the positive port facing upward. The sensor was then gradually rotated clockwise 12 degrees and output was recorded. Next, the sensor was rotated 12 more degrees and output was recorded. This process was continued with the interval of 12 degrees until the sensor was vertical. The rotation continued passed the vertical point. From this point on the negative port was facing upward. Rotation and acquisition of data continued until the sensor was horizontal with the negative port facing upward. This rotation was then reversed and the transducer was rotated back to the starting point. Careful attention was paid to the region corresponding to zero pressure (in both directions of rotation) to assure that no "oil canning" took place.

This experiment utilizes the weight of the diaphragm and gravity to generate a precise pressure. While the diaphragm is vertical, the weight of the diaphragm has no effect on the position of the diaphragm. The diaphragm will remain in its neutral axis, un-deflected. As the sensor is rotated away from the vertical, the weight of the diaphragm will cause a deflection of the diaphragm. This deflection is proportional to the sine of the angle from vertical position. Rotation where positive port is upward will simulate positive pressurization and rotation where negative port is up will simulate negative pressurization. The thickness of the diaphragm is measured to calculate the equivalent pressure it will generate.

In order to check for any possible abrupt discontinuity (oil canning) of the diaphragm, this test was started with the diaphragm horizontal, rotated through vertical position and continued to horizontal such that sensor had completely turned over. This test was performed slowly and at no time was the direction reversed. After the sensor was rotated 180 degrees, its rotation was reversed and output was again recorded at intervals of every 12 degrees until the starting position was reached. The output was carefully monitored as the transducer was slowly rotated in both directions, and at no time was any indication of "oil canning" observed (see graph 1). The resolution of the system was .00002 inches of water.

This test is presumed to be very accurate since it involves only gravity and angles. The only source of inaccuracy is the levelness of this set up and accuracy of reading the angle. These possible inaccuracies will have no significant effect in the intended application.


DP103-06 IS TILTED FROM VERTICAL ORIENTATION
0.0200
0.0150
0.0100
0.0050
0.0000
-0.0050
-0.0100
-0.0150
-0.0200
-0.0200
-0.0150
-0.0100
-0.0050
0.0000
0.0050
0.0100
0.0150
0.0200
output in equivalent inches of H2O
INPUT PRESSURE EQUIVALENT(INCHES OF H2O)
asending
desending

Graph 1

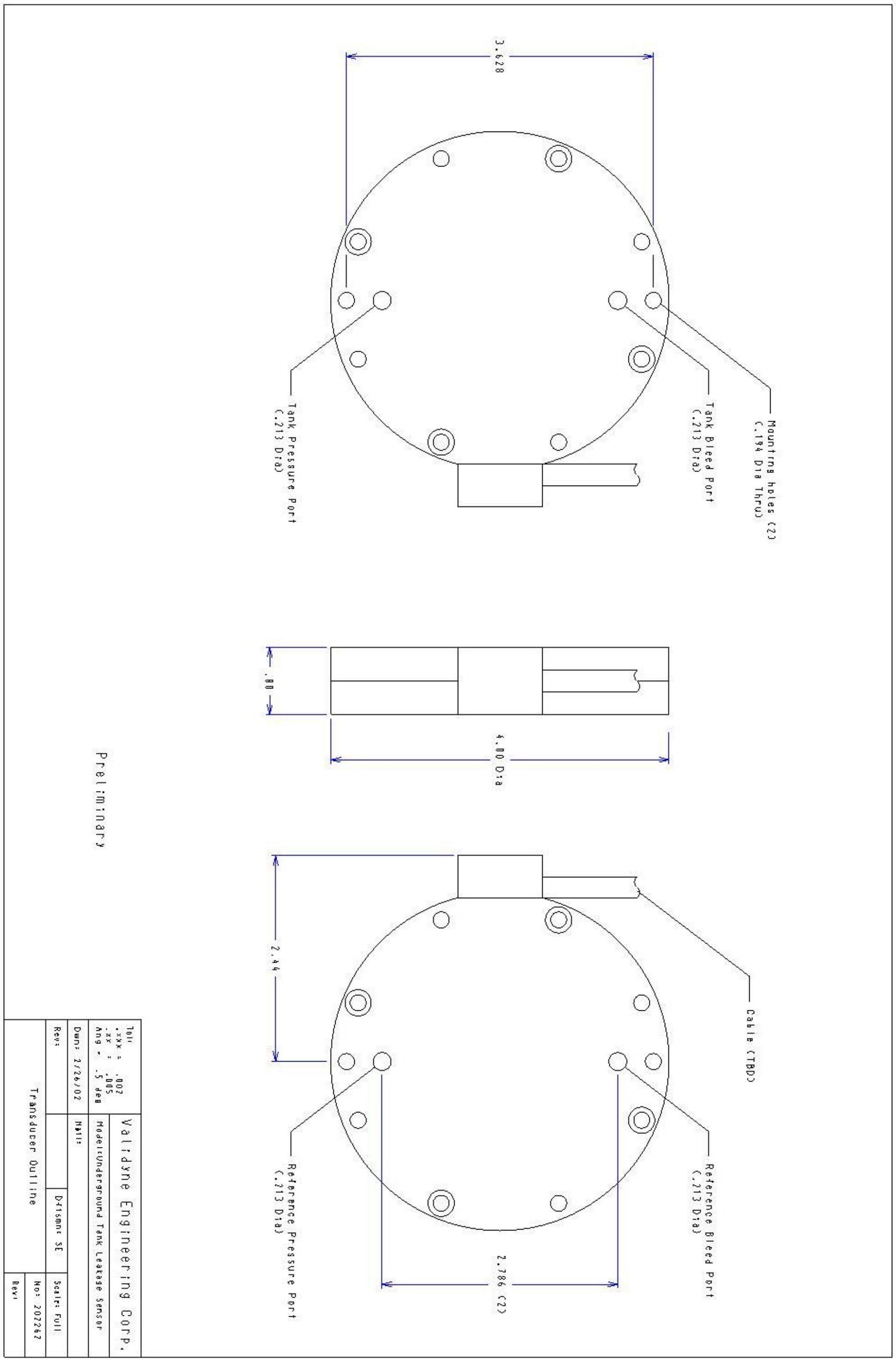


Figure 1 - Proposed DP103 Outline Drawing

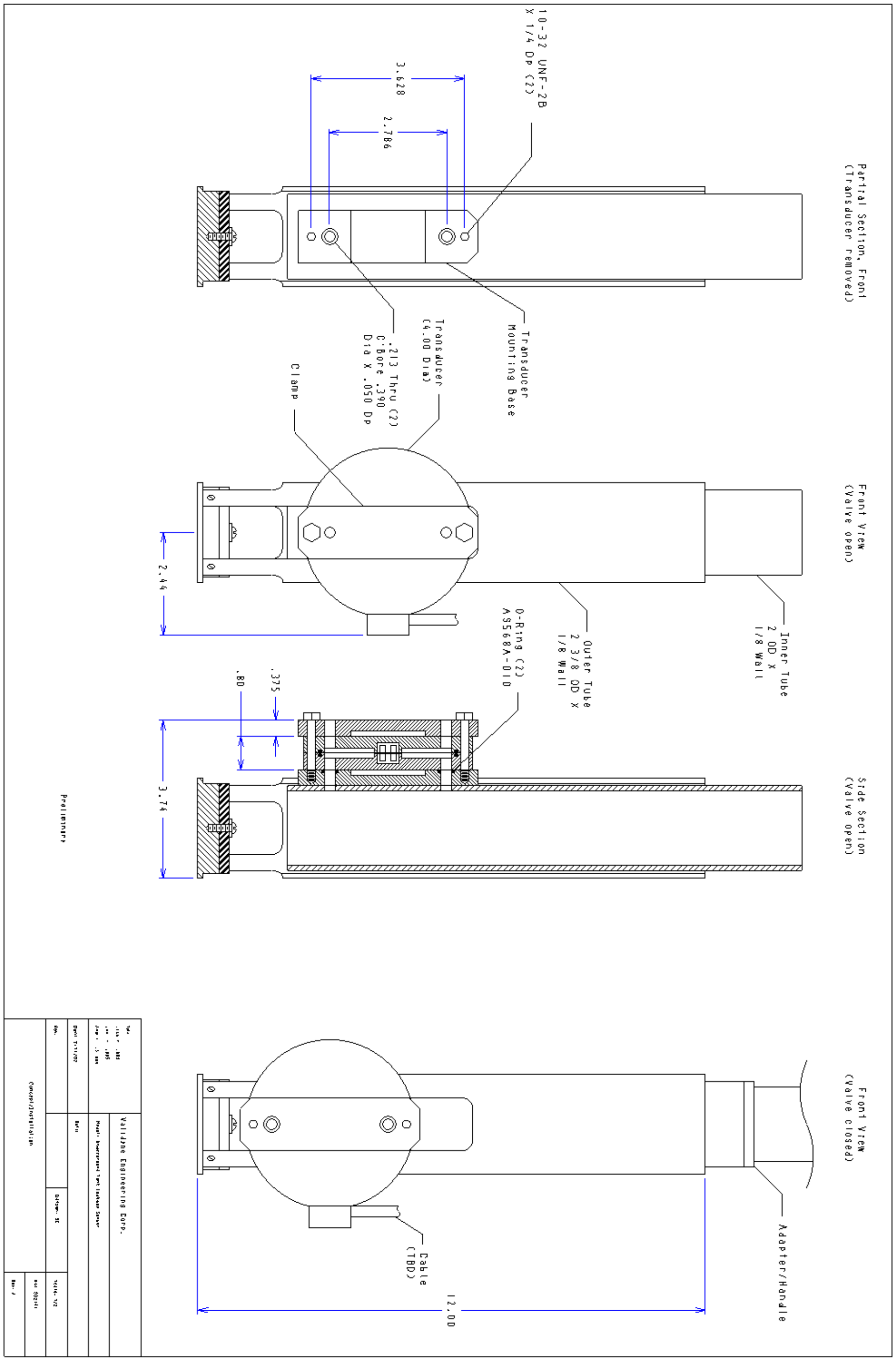


Figure 2 – Concept/Installation Drawing

Conclusion

Based on the tests performed, it appears that a modified Validyne DP103 together with a Validyne P432 carrier demodulator will perform adequately to achieve the desired tank leak detection function desired. More extensive and detailed tests will be performed in Phase Two of the project.

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May 20, 2002

Fuel Tank Leak Detection System
Phase Two Report
Design and Development

In this phase Validyne has designed and built a prototype that is of production intent and tested with electronics to demonstrate its suitability to the project. Validyne will deliver detailed design drawings along with performance and verification test data and the status of FM certification. In addition, firm product pricing and a delivery schedule will be provided.

Drawings Provided

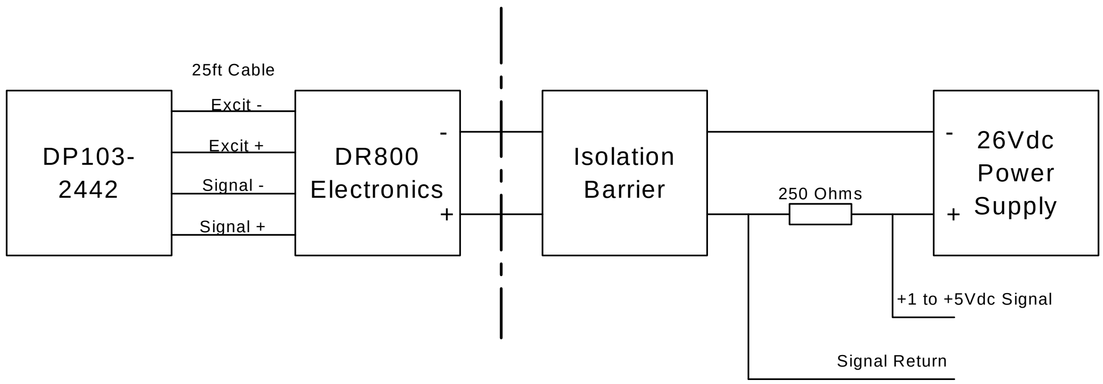
Concept/Installation Drawing. See figure 1
Outline Drawing. See figure 2

Description of Prototype DP103 Transducer

The transducer is a specially machined DP103. This transducer has been assigned a model number of DP103-2442. The external dimensions are 4 inches in diameter by .75 inches thick. The internal cavity area has been increased to promote the evacuation of air bubbles. There are two holes in each side of the transducer. The lower hole allows liquid to enter in the transducer and the upper hole allows air bubbles to escape out of the sensor cavity. The two openings in each side of the sensor are placed at lowest and highest locations of the internal cavities to promote the bleeding to the air. The two bleed ports in each side of the transducer are round holes. These round holes will be horizontal during the test. The transition from these straight thru ports to the outside is by a manifold that will be clamped against the flat surface of the side of the transducer. In production this manifold will have an “O” ring seal against the side of the sensor. The prototype testing uses teflon gaskets.

Description of Electronics Package

The electronics used with the DP103-2442 will be a DR800 circuit board. This electronics provides excitation and signal condition with a 4 to 20ma two wire output. zero to full scale and is powered with 26Vdc supply. The DR800 was FM approved until the isolation barrier became obsolete. A new isolation barrier has been chosen and Validyne is in the process of getting certification reinstated. See drawing below.



Tests Performed

The following tests where performed using the DP103–2442 transducer and a Validyne industrial electronics DR800 for signal conditioning. A 25 foot long cable was used to connect the transducer to the DR800. This combination will be called the system in this report. The DR800 utilizes 4 ma to 20 ma output, therefore 4 ma represents zero pressure and 20 ma is full pressure of 0.15 inches of H_2O. This current was fed through a 250 ohm resistor to convert the current to a voltage so that the output is 1.0 volts dc at zero and 5.0 volts at full scale.

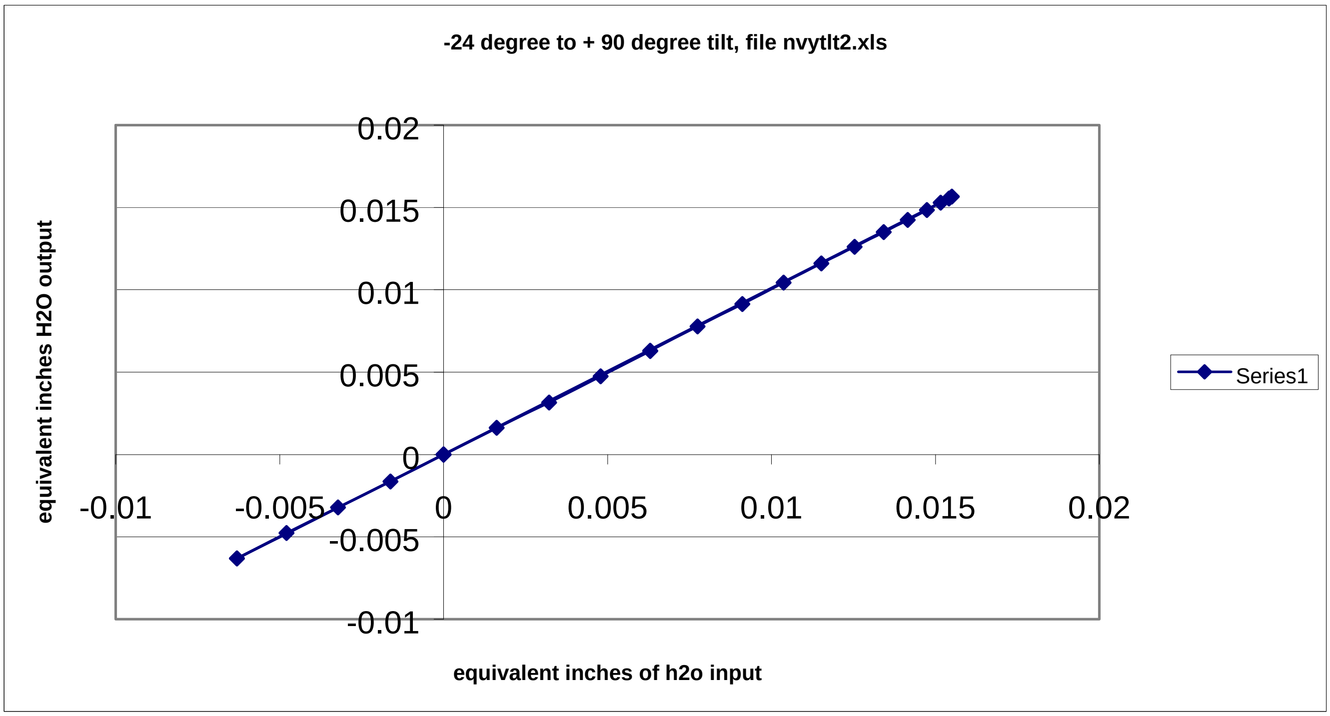
- Manual Calibration
- Plot output of transducer by tilting sensor from vertical in 6 degree increments
- Plot output of transducer by tilting from vertical in 1 degree increments
- Output Noise of System
- Air Bleed Test

Manual Calibration:

The transducer was calibrated for a full scale output of 0.14 inches of water using an air pressure source. In this test we established that the sensor is linear, has sufficient output, and is symmetrical about zero pressure. This test was performed to verify the full scale range of the transducer and that there are not any deficiencies that would prohibit its use. The output of this transducer was shown to 31.13 mv/v positive full scale and -31.31 mv/v negative full scale. The zero balance was 4 mv/v. The results of this test where that output, symmetry and balance were within specification

Record output of transducer by tilting from vertical in 6 degree increments:

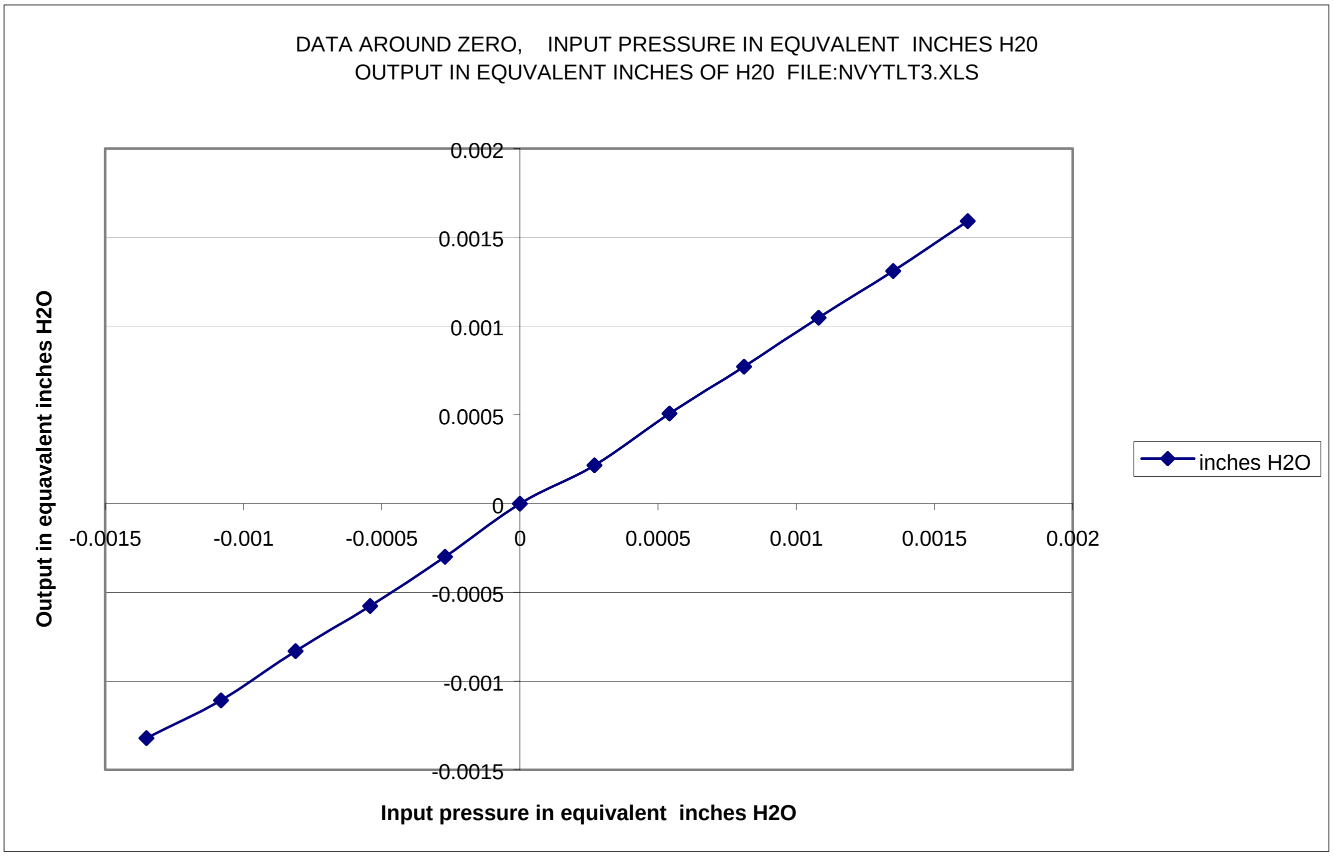
Transducer was installed on an indexing fixture as shown in photo 1. The indexing fixture was installed in vertical orientation such that the plane of the transducer was in vertical orientation as well (see photo 2). The weight of diaphragm and the angle of the vector from vertical provides for an accurate repeatable method of applying a known force to the diaphragm of the transducer. Readings were taken once a second with the transducer diaphragm in a vertical position. The transducer was then rotated so that the plane of the diaphragm was at negative 24 degrees from vertical and readings were taken once a second in that orientation. The transducer was then tilted toward vertical in increments of 6 degrees and readings were taken once a second at each 6 degree interval until the positive 90 degree position (see photos 3 & 4). See graph below.



The results of this test where that output of sufficient amplitude and linear. Data was taken mainly in the positive direction since the electronics is configured for positive calibration and this will provide the most resolution.

Plot output of transducer by tilting from vertical in 1 degree increments:

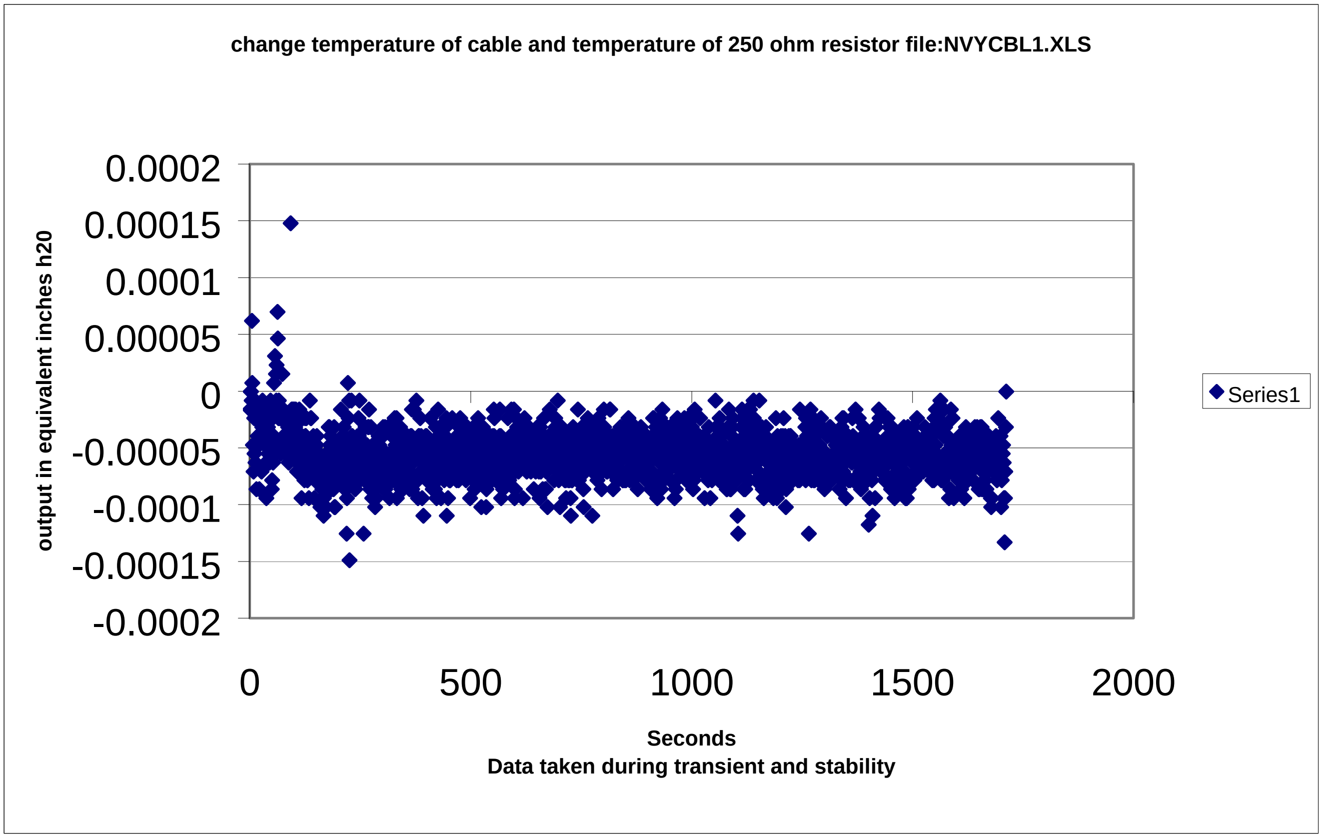
This test is identical to the test above but focuses on a smaller area around zero output which is where the system will typically operate in the tank level application. This is a very fine calibration where 1 degree corresponds to a pressure of about 0.00025 inches of water. Readings were taken once a second with the transducer diaphragm in a vertical position. The transducer was then rotated so that the plane of the diaphragm was at negative 6 degrees from vertical and readings were taken once a second in that orientation. The transducer was then tilted toward vertical in increments of 1 degree and readings were taken once a second at each 1 degree interval until the positive 6 degree position. See the graph below.



The results of this test indicated there was no discontinuity in the output and the slope was constant thru zero.

Output Noise of System

To test the level of signal noise out of the system its output was recorded once a second for 24 minutes with no pressure applied. The level of noise recorded is within acceptable limits and in addition this small noise will be significantly reduced when the data is averaged. See the graph below.



The results of this test indicated the noise level was within ±0.00005 inches of water and there where no large data spikes over the 24 minutes that the test was run.

Air Bleed Test

A second transducer was utilized for this test so that the original transducer could be kept dry. Once a sensor is wetted with a liquid media, we cannot be certain that that entire media has been removed from the sensor. Steps were taken to prevent any contaminants from getting into the sensor, which will be given to the customer. Since we do not have any jet fuel on our premises it was decided to use a second transducer for this test. This test was performed by holding transducer in a vertical position and recording the balance. The balance is recorded on the bench, after immersion into liquid, and after bubbles were removed. The sensor was then removed from the liquid and the balance was recorded on the bench again. The results of this test showed that some air bubbles where still being trapped in the bleed ports. It was learned that the bleed path is most effective if it is slanted. It is expected that a slanted bleed port will provide more certainty in removing

bubbles. Once the bubbles were removed, sensor balance is recovered. Repeating the balance is the best indicator of repeatability of sensor performance. The DP103-2442 will be modified to slant the bleed ports and this test will be repeated.

Conclusion

The testing performed on the prototype DP103-2442 has shown that it meets the requirements for the tank leak detection system. The prototype provided will be modified from the current design to enhance its bleed capabilities. This change will be the only required modification from the current design and does not effect any of the other performance capabilities. The bleed test will be repeated after the bleed port modification to insure proper operation. System will be delivered after this last test.

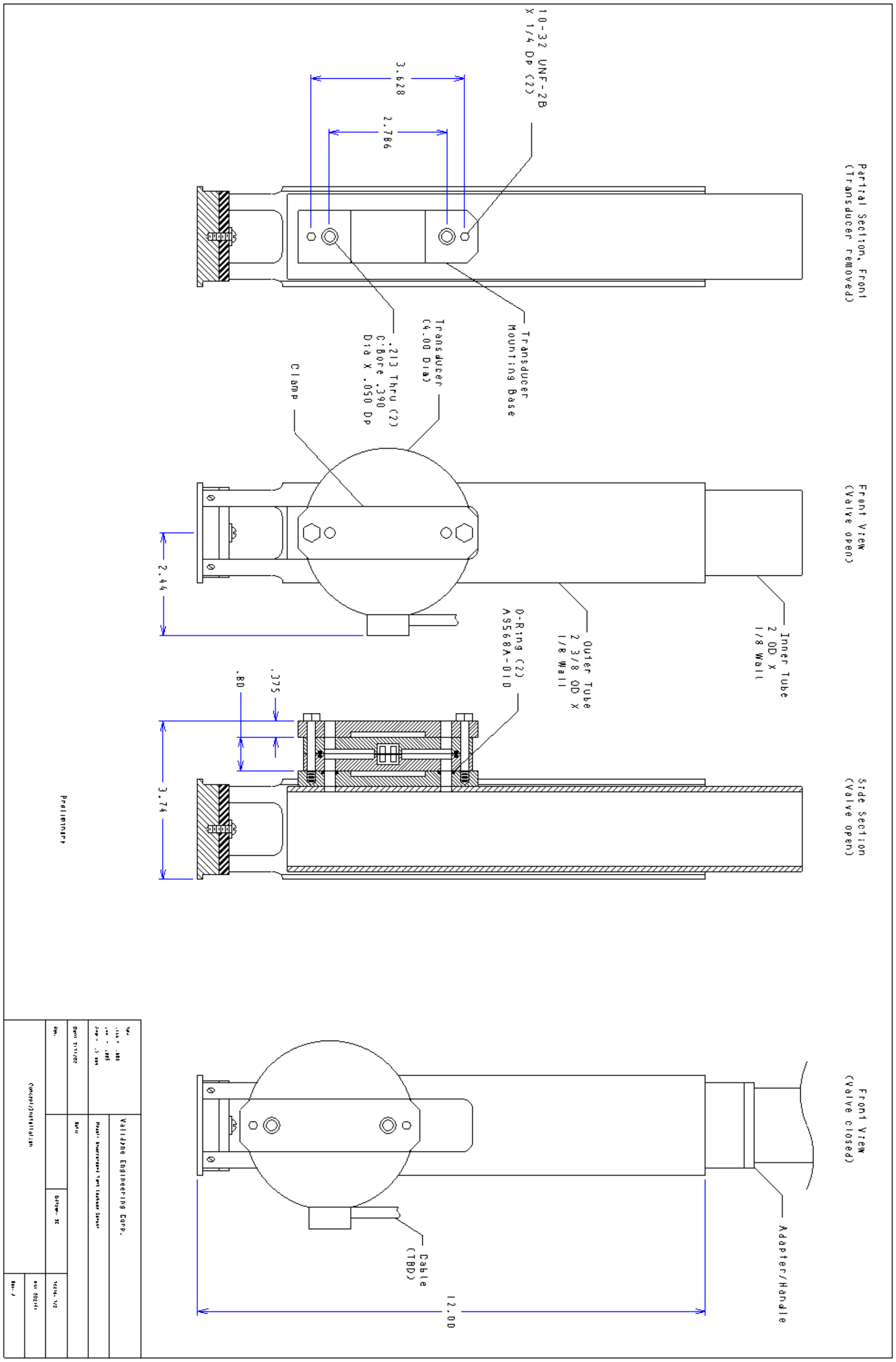


Figure 1 Concept/Installation

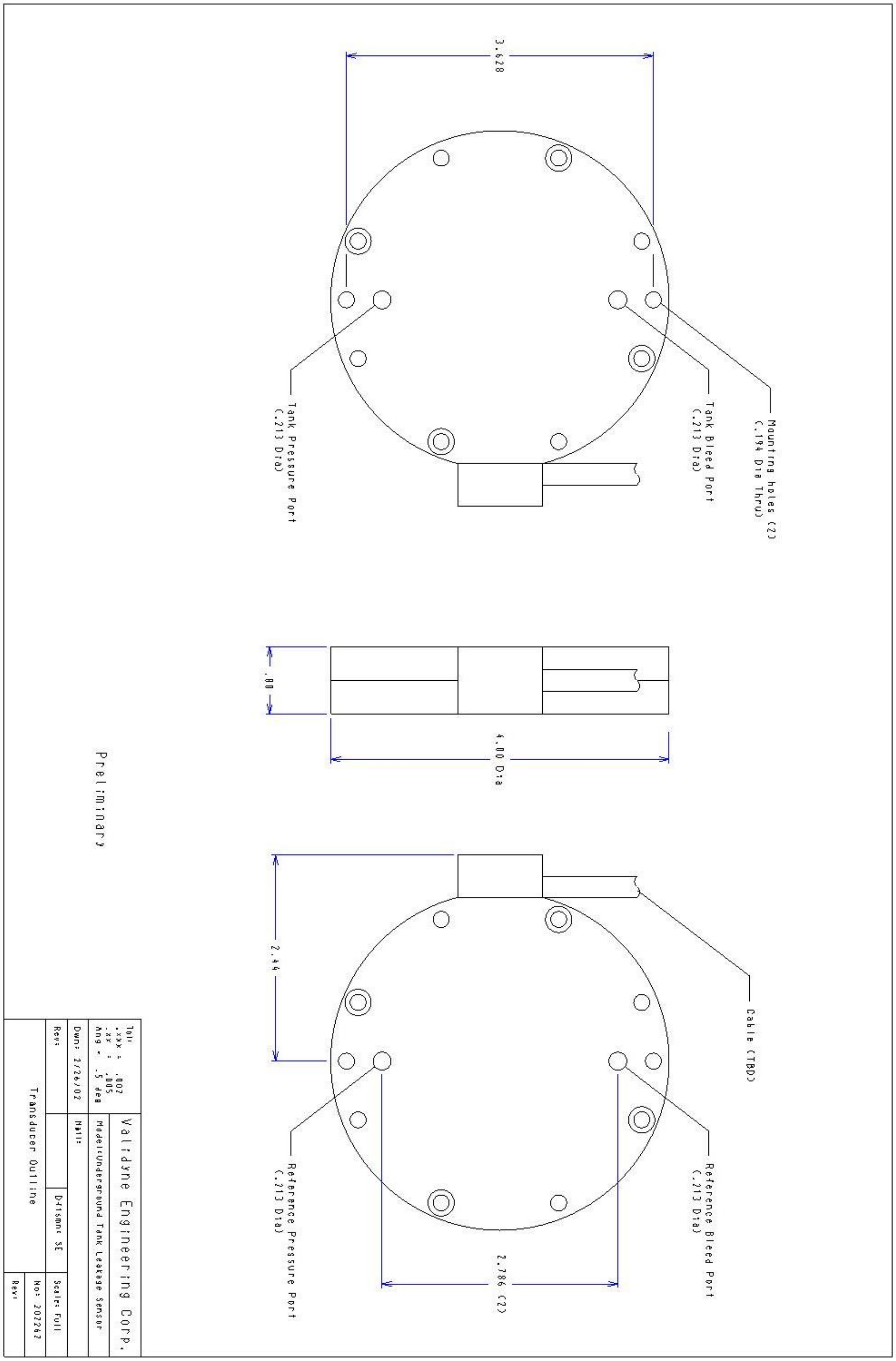


Figure 2 Outline

Photo 1 Mounting on Indexing Fixture

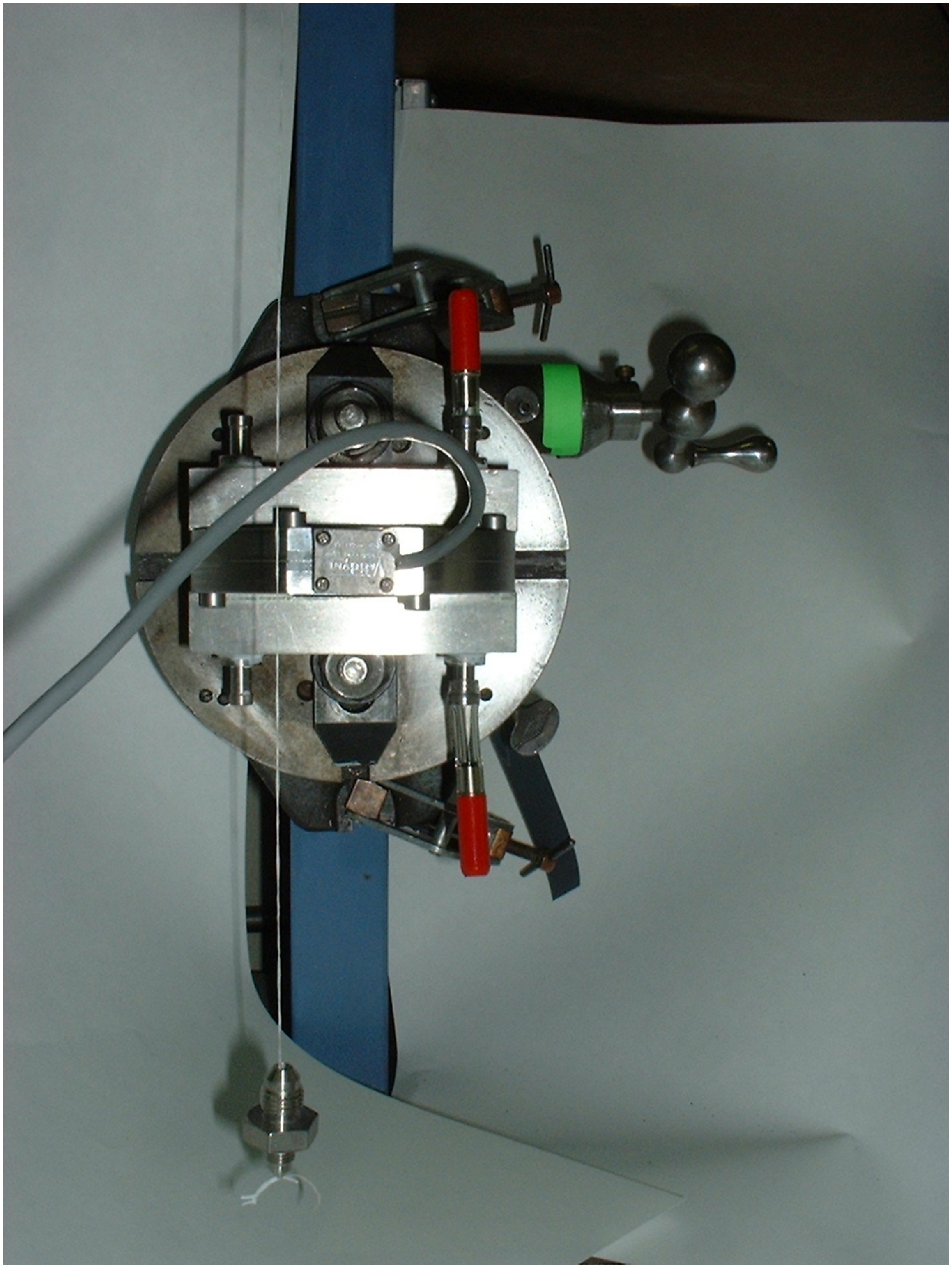


Photo 2 Vertical Mounting

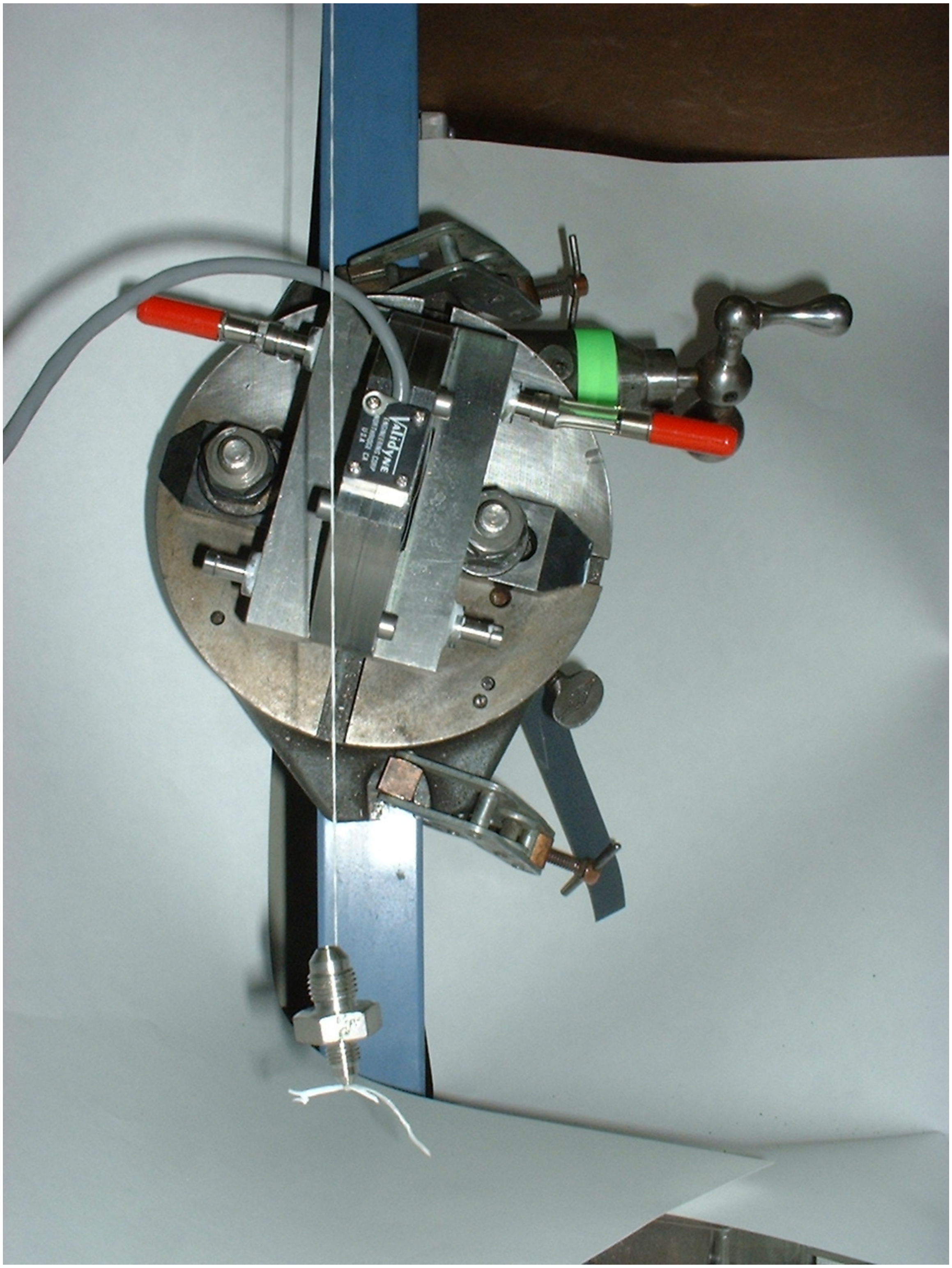


Photo 3 Rotation of Tilt Angle

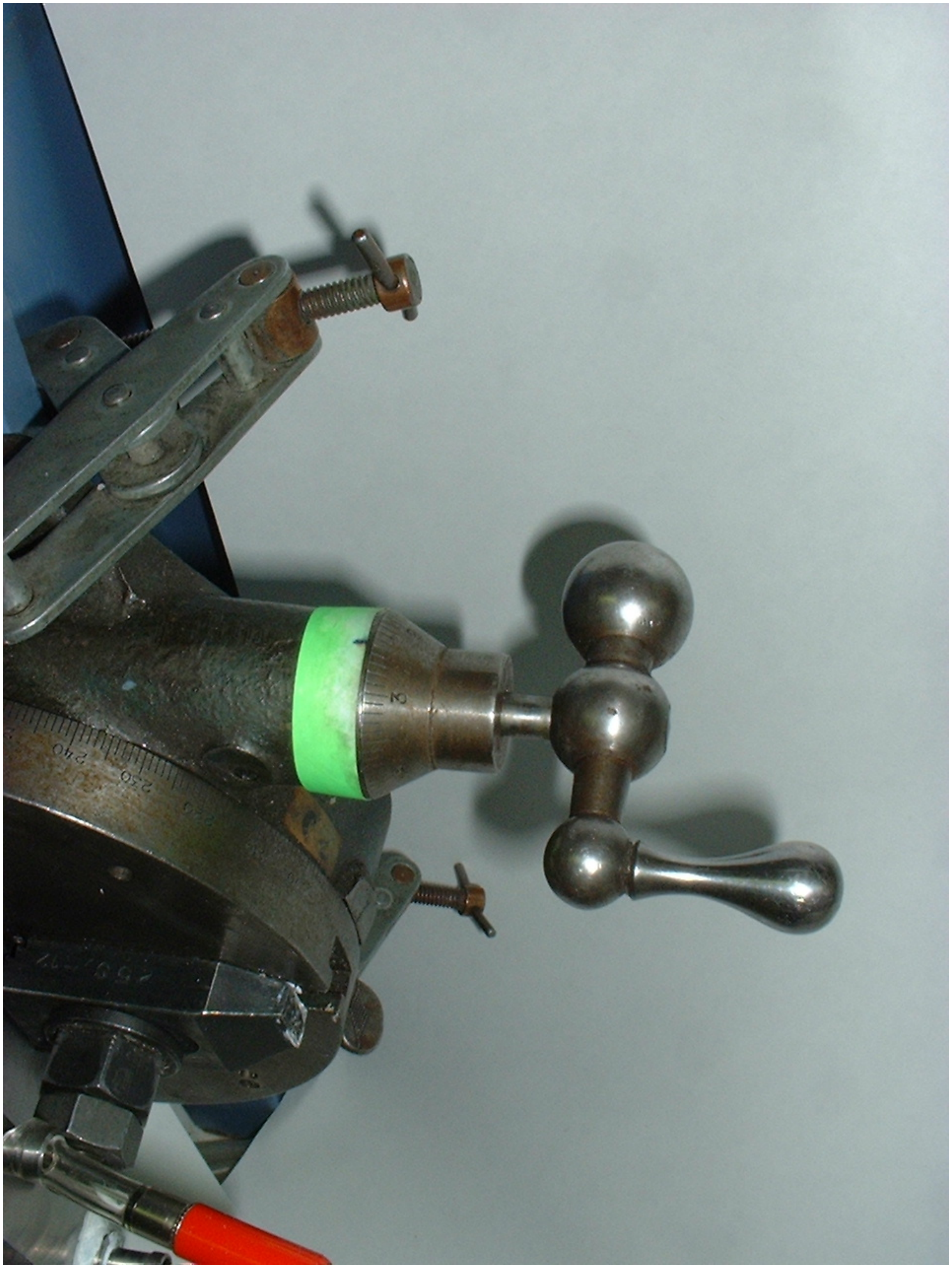


Photo 4 Fixture Tilt Control

APPENDIX B

Evaluation of the Portable Rapid Test (PRT) Tank Leak Detector for Tanks Up to 75,000 Gallon Capacity

Final Report

PREPARED FOR:

Naval Facilities Engineering Service Center

April 6, 2006
Rev 4/6/10

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Evaluation of the Portable Rapid Test (PRT) Tank Leak Detector for Tanks Up to 75,000 Gallon Capacity

Final Report

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April 6, 2006
Rev. 4/6/10

Preface

This report describes a third independent evaluation of the Portable Rapid Test (PRT) Bulk Tank Leak Detector as a leak detection system for tanks up to 75,000 gallons. Testing was conducted at the Pacific Missile Range, Barking Sands) located on Kauai during November and December 2004. The test tank was a nominal 50,000-gallon tank that was 59 ft long and 12 ft in diameter. The leak simulations, data collection, data analysis, and reporting were conducted by Ken Wilcox Associates, Inc.

This report was prepared by Dr. H. Kendall Wilcox. Technical Questions regarding this evaluation should be directed to Mr. William Major, NAVFAC ESC at (805) 982-1816.

KEN WILCOX ASSOCIATES, INC.

H. Kendall Wilcox

H. Kendall Wilcox, Ph.D.
President
April 6, 2006
Rev. 4/6/10

Table of Contents

1.0 Introduction

This report describes an independent evaluation of the PRT Tank Leak Detector. This system has been developed by the Naval Facilities Engineering Service Center (NAVFAC ESC), Vista Engineering and Validyne Engineering, to conduct leak-detection tests on tanks up to 75,000 gallons capacity. The evaluation was conducted in a nominal 50,000-gallon cylindrical bulk underground storage tank. Twelve tests were conducted in November and December with nominal leak rates ranging from zero to 0.3 gallons per hour. The calculations and results contained in this report use the procedures described in the bulk tank protocol.[1]

2.0 Description of the Test Facility

Testing was done at the Barking Sands Pacific Missile Range, Kauai, Hawaii. The tank was a steel shop-constructed tank with a nominal capacity of 50,000 gallons. The tank contained Jet A and had a nominal length of 59 ft and a diameter of 12 ft.

Openings in the tank were available for the PRT system equipment and for the KWA leak simulation equipment. The test tank was made available to KWA staff 24 hours a day for the duration of the evaluation. Fuel was transferred into and out of the tank using the fuel farm pumping systems. The tanks was filled to a nominal level of 95% for all of the 12 tests that were conducted. The level was reduced to 50% and refilled again to 95% between each pair of tests. No induced temperature changes were provided for these tests, but some small differences in temperature were observed during the testing.

KWA staff was present for the duration of the evaluation and defined the testing schedule of the evaluation.

3.0 Description of the PRT Tank Leak Detector

The PRT leak detection system comprises a tank fuel level sensing unit, signal conditioning, and laptop computer. The tank level sensing unit has a vertical reference tube that spans the full height of the tank. This reference tube has a straight or shaped cross-sectional area that matches, with a constant ratio, the cross-sectional shape of the test fuel tank. The bottom section of the reference tube is about 8 – 12 inches and is detachable from the main upper reference tube. Attached to the bottom section of the reference tube is sliding seal that is spring loaded to be normally open. The sliding seal is designed so that, when resting on the bottom of the test tank, the weight of the reference tube will overcome the sliding seal spring force and the sliding seal will close the bottom of the reference tube so no additional fuel can enter into the reference tube. A differential pressure transducer is attached to the side of the bottom section of the

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[1] "Alternative Test Procedures for Evaluating Leak Detection Methods: Mass-based and Volumetric Leak Detection Systems for Bulk Field-constructed Tanks," Ken Wilcox Associates, November 2000.

reference tube and is adjacent to the sliding seal. The pressure transducer measures the pressure difference between the height/mass of the fluid in the reference tube and the height/mass of the fluid in the test tank. To minimize fluid cavity areas that can potentially trap or contain vapor bubbles, the pressure transducer is mounted directly to the reference without the use of external tubing. To provide quick thermal stabilization, the pressure transducer body is also of a type that can be directly immersed in the test tank fuel without use of a containment vessel. The bottom section of the reference tube, the sliding seal, and the differential pressure transducer comprises a modular unit that can be attached to any length of upper reference tube so that the modular unit can be adapted to any tank configuration.

The electrical conductors are hermetically sealed to the differential pressure transducer and are contained in a fuel resistant jacket. The conductors/jacket is attached to the outside of the reference tube, runs along the full length of the reference tube, and has approximately 20-30ft of additional cable length available for routing to the electronics package outside the test tank. The electronics package consists of a signal conditioner, power supply, terminal block and PCMCIA A/D card. The signal conditioner maintains an intrinsically safe 4 – 20ma supply current to the differential pressure transducer. The pressure transducer modifies the magnitude of the supply current (i.e., the analog test signal) in relation to actual pressure differentials developed between the reference tube and the test tank. The analog test signal is then output from the signal conditioner as a 1 – 5 Volt signal. This analog signal is then fed to a laptop computer PCMCIA A/D card for analog to digital conversion. Leak detection software installed in the laptop reads the PCMCIA A/D card digital signal and provides signal conversion to pressure change over time or gallon/hr leak rates, input of conversion factors, real time graphing of test leak rate, test start and stop functions, test parameter description notes and real time data saving capabilities.

4.0 Leak Simulation Equipment

The leak simulation procedures used in the evaluation were those described in the bulk tank protocol, which are also identical to those described in the standard EPA protocols for ATG and volumetric systems.

Leak simulations were conducted by removing fuel from the stilling well of the tank at a steady rate using a peristaltic pump. The induced leak rate was calibrated volumetrically at the beginning of the test and the total volume removed from the tank was used to calculate the induced leak rate. Testing at each leak rate continued for approximately 24 hours and was assumed to be constant during this time period.

The volume of fuel removed was measured gravimetrically using a balance with a resolution of 2 grams. This mass was then converted to volume using the density of the fuel in the tank. The density was determined by weighing a know volume (2 liters) of fuel.

5.0 Description of the Evaluation Procedures

NAVFAC ESC staff installed the PRT system in the test tank in its normal configuration. Testing was carried out using the manufacturer's normal test routine. Leak simulations were induced using a peristaltic pump to remove small volumes of fuel from the tank over a 24-hour period. The leak rate reported by the PRT was compared to the actual induced leak rate. A statistical analysis of the data was used to determine the performance characteristics of the test method.

A total of 12 tests were conducted on the PRT Leak Detector. Product removals and deliveries were made during the evaluation after each pair of tests. Leak simulations were conducted for 24 hours for each of the 12 tests. For these tests, durations of tests of 5 hours were selected using the data segment from 0300 to 0800.

6.0 Test Conditions and Results

The test conditions and test results for the 5 hour tests are shown in Tables 1 and 2.

Table 1. Testing Conditions – 5-Hour Test

Test No.	Date at Completion of Last Fill	Time at Completion of Last Fill	Wait Time to 24-hr Test	Wait Time to 5-hr Test	Product Level	Product Temp. Dif.	Date 5hr Test Began	Time 5hr Test Began	Date 5hr Test Ended	Time 5hr Test Ended	Test Time
	(m/d/y)	(military)	(hours)	(hours)	(%)	(Deg F)	(m/d/y)	(military)	(m/d/y)	(military)	(hrs)
1	N/A	N/A	N/A	N/A	95	N/A	11/4/2004	0300	11/4/2004	0800	5
2	N/A	N/A	N/A	N/A	95	N/A	11/6/2004	0300	11/6/2004	0800	5
3	11/8/2004	1300	50	63	95	N/A	11/11/2004	0300	11/11/200	0800	5
4	11/8/2004	1300	76	87	95	N/A	11/12/2004	0300	11/12/200	0800	5
5	11/12/2004	1600	17.62	23.62	95	N/A	11/13/2004	1537	11/13/200	2037*	5
6	11/12/2004	1600	44.17	59	95	N/A	11/15/2004	0300	11/15/200	0800	5
7	11/16/2004	1230	5.25	14.5	95	N/A	11/17/2004	0300	11/17/200	0800	5
8	11/16/2004	1230	29.5	38.5	95	N/A	11/18/2004	0300	11/18/200	0800	5
9	12/2/2004	1200	23.75	39	95	N/A	12/4/2004	0300	12/4/2004	0800	5
10	12/2/2004	1200	47.5	63	95	N/A	12/5/2004	0300	12/5/2004	0800	5
11	12/6/2004	1230	47	62.5	95	N/A	12/9/2004	0300	12/9/2004	0700**	4
12	12/6/2004	1230	71	86.5	95	N/A	12/10/2004	0300	12/10/200	0800	5

* Test #5 - 1537 to 2037 test period used due to site generator malfunction stopping induced leak rate prior to 0300 test period.
** Test #11 - Calibrations were run during 0700 - 0800 so data set analyzed was reduced by 1-hr

Table 2. Leak Rate Data – 5-hr Test

Test No.*	Wait Time	Product Level	Nominal Leak Rate	Measured Leak Rate	Induced Leak	Measured - Ind. Leak Rate
-	(hours)	(%)	(gal/h)	(gal/h)	(gal/h)	(gal/h)
1	N/A	95	0.2	0.084	0.166	-0.082
2	N/A	95	0.3	0.198	0.299	-0.101
3	63	95	0	-0.093	0	-0.093
4	87	95	0.1	0.068	0.13	-0.062
5	17.12	95	0.05	-0.031	0.057	-0.088
6	35	95	0	-0.075	0	-0.075
7	14.5	95	0.3	0.228	0.318	-0.09
8	38.5	95	0	-0.09	0	-0.09
9	39	95	0.2	0.068	0.178	-0.11
10	63	95	0.1	-0.001	0.104	-0.105
11	62.5	95	0.05	-0.079	0.048	-0.127
12	86.5	95	0.05	-0.045	0.067	-0.112

* No tank fuel temperature differential measurements were recorded for these series of tests.

7.0 Calculations and Results

This section describes the data analysis procedures that were used to characterize the performance of the PRT system. The results of the calculations are also included in the discussion. A summary of the results is provided in Table 4.

7.1 Basic Statistics

Mean Squared Error (MSE)
The MSE was calculated to be 0.00923 $(gal/h)^2$ for the 5 hour test.

Standard Deviation
The standard deviation was calculated to be 0.0177 for the 5 hour test.

Variance
The variance was calculated to be 0.000312 for the 5 hour test.

Bias
The bias is estimated by the mean of the differences:

$$B = \Sigma D_i/N, \qquad (6\text{-}2)$$

where N is the number of tests (usually 12) in the evaluation and the summation is over all differences. The variance of the differences is found using the formula

$$V = \Sigma (D_i - B)^2/(N-1). \qquad (6)$$

The bias of the system was found to be -0.0946 gal/h for the 5 hour test

This bias is fairly large. The most likely source of the bias is an in-leak from some part of the piping system leading to or from the tank. The piping sloped from the source tank to the test tank. Efforts to find and remove the source of the bias were unsuccessful.

7.2 Performance Characteristics

Procedures for determining the P_D, P_{FA}, and MDL are contained in the standard EPA test protocol for volumetric systems[1] and are summarized below.

Calculation of Probability of False Alarm (P_{FA})
The probability of a false alarm, P_{FA}, is the probability that the measured leak rate will exceed the threshold for declaring a leak when the testing is done on a tight tank. If C denotes the threshold, then the probability of a false alarm is estimated from

[1] Standard Test Procedures for Evaluating Leak Detection methods: Volumetric Tank Tightness Testing Methods", pages 28-33 describe procedures for calculating the P_D, P_{FA}, and MDL.

$$P_{FA} = P[t > (C - B)/S]. \qquad (6\text{-}5)$$

This probability is calculated by computing the term (C – B)/S using the specified threshold C and the bias, B, and standard deviation, S, computed from the test results. The result is used with a t-distribution with 11 degrees of freedom. A table of the t-distribution is used to find the probability that a t-statistic with 11 degrees of freedom exceeds the computed value. The PFA for a leak of 0.1 gal/h was determined to be 0.8 percent for the 5 hour test.

Calculation of Probability of Detection (PD)

The probability of detecting a leak depends on the specific leak rate. For a leak rate of size R, the probability of detection, P_D, is given by

$$P_D = P[t > (C - R - B)/S]. \qquad (6\text{-}6)$$

In the formula, the threshold, C, is specified as before, the leak rate for which the P_D is calculated is R, and B and S are calculated from the test data as before. The term (C – R – B)/S is computed. A t-distribution with 11 degrees of freedom is used to look up the probability that a t-statistic exceeds the calculated value. The PD was determined to be 99.2 percent when the threshold was set at -0.045 gal/h. This threshold was adjusted for the bias.

Setting the Threshold

The threshold (C) may be set to give a specified probability of false alarm. For example, if a P_{FA} of 5% is desired, use the t-table to determine that the probability is 5% that a t-statistic with 11 degrees of freedom will exceed 1.796. The effect of any bias (B) in the data must be corrected when setting the threshold. The bias (B) and standard deviation (S) are calculated from the test data. To choose C, set

$$(C - B)/S = 1.796 \qquad (6\text{-}7)$$

if B is not zero the equation becomes

$$C = (1.796)(S) + B$$

If the bias is not significant, the equation reduces to

$$C = (1.796)(S) \qquad (6\text{-}9)$$

The three variables, PD, PFA and threshold may be varied with in the range of a P_D of at least 95% and a P_{FA} of not less than 5%. Table 3 illustrates some of the possible combinations that might be useful to a vendor.

Table 3. Summary of the P_D and P_{FA} Results – 5 Hour Test

Method	Leak Rate (gal/h)	Threshold (gal/h)	P_D (%)	P_{FA} (%)
c	0.10	-0.045	99.1	0.8
c min	0.10	-0.063	99.8	4.9
c max	0.10	-0.026	95.0	0.1

<u>Minimum Detectable Leak Rate</u>
For a specified threshold C, the smallest leak rate that can be detected with a specified probability, e.g. 95%, can be determined as the minimum detectable leak rate, MDL. This is accomplished by using a t-table to find the probability that a t-statistic with 11 degrees of freedom will exceed –1.796. Set

$$(C - R - B)/S = -1.796 \qquad (6\text{-}10)$$

The value of R that solves the above equation is the MDL for the threshold C.

$$MDL = C - B + 1.796\,(S) \qquad (6\text{-}11)$$

The value of R that satisfies the previous equation using the threshold for a 5% P_{FA} is the MDL for a 5% P_{FA} and a 95% P_D. This is the smallest leak rate that is detectable with 95% probability using the threshold C. Note if the bias is not statistically significantly different from zero it is taken to be zero.

<u>Maximum Temperature Differences</u>
Since there was no heating or cooling capability for this evaluation the temperature differences between product added to fill the tank and product already in the tank were less than 1 degree F. These differences were due to natural effects of weather, fuel transfers or other conditions. It is likely that much larger temperature differentials will work with this system.

<u>Stabilization Time</u>

The test for adequate stabilization time compares the measured leak rate for first test of a pair of tests with the measured leak rate of the second test of the pair. If the difference between the two tests is significant, the stabilization time is not adequate. All indications are that an average stabilization time is 5 hr 20 min.

<u>Test Duration</u>
The average test time for the 5 hour test was 4.9 hours. One of the 5 hour tests was unintentionally terminated 1 hour short. The vendor specifies that the 5 hour test

should be conducted for at least 5 hours irregardless of the average time reported in this evaluation.

Maximum Allowable Tank Size

The federal protocols specify that the maximum allowable tank size is 1.5X the size of the tank used for the evaluation. The tank used had a nominal capacity of 50,000 gallons, resulting in a maximum tank size of 75,000 gallons.

Water Detection Mode

The water detection mode calculations do not apply to the PRT. The PRT is a mass-based system, which will detect increases and decreases in mass in the tank. Water leaks into or out of the tank are detected as changes in mass and the tank operator is alerted if a problem exists.

Table 4. Performance Parameters for the PRT Tank Leak Detector – 5 Hour Test

Parameter	Value
Number of Test Conducted for Evaluation	12
Maximum Tank Size	75,000 gal
Maximum Allowable Temperature Difference	Not determined for this Evaluation
Average Waiting Time After Filling Minimum	5 hrs 20 min
Minimum Detectable Water Level (in)	Not determined for this Evaluation[1]
Minimum Water Level Change (in)	Not determined for this Evaluation[1]
Basic Statistics	
Mean Squared Error	0.00923 gal^2/h^2
Variance	0.000312 gal^2/h^2
Standard Deviation	0.0176 gal/h
Bias	-0.0946 gal/h
Performance Data	
Leak Rate	0.10 gal/h
Threshold	-0.0446 gal/h
Probability of False Alarm (PFA)	0.8 %
Probability of Detection (PD)	99.2 %
Minimum Threshold for 5% PFA	-0.0628 gal/h
Minimum Detectable Leak Rate for 95% PD	0.0817 gal/h
Time to Detect a 0.2 gal/h Water Incursion (hrs)	Not determined for this Evaluation

1 The ingress or egress of water has the same effect as fuel loss or gain for a mass based system. It is not necessary to have a separate measurement.

Attachment 1

Report Forms for
PRT Tank Leak Detection System

Results of U.S. EPA Alternative Test Procedures

Bulk Field-Constructed Tank Mass-Based Leak Detection Method

This form describes the performance of the leak detection method described below. The evaluation was conducted by the equipment manufacturer or a consultant to the manufacturer according to a modification of the U.S. EPA's "Standard Test Procedure for Evaluating Leak Detection Methods: Volumetric Tightness Testing Methods." The full evaluation report also includes a form describing the method and a form summarizing the test data.

Tank owners using this leak detection system should keep this form on file to provide compliance with the federal regulations. Tank owners should check with State and local agencies to make sure this form satisfies their requirements.

Leak Detection Method Description

Name PRT-1

Version number v1.0

Vendor(s)

NAVFAC ESC 1100 23rd Avenue (street address) Port Hueneme, CA 93043-4370 (city) (state) (zip) (805) 982-1618 (phone)	Vista Research, Inc. 100 View Street (street address) Mountain View, CA 94041 (city) (state) (zip) (650) 966-1171 (phone)

Validyne Engineering 8626 Wilbur Avenue (street address) Northridge, CA 91324 (city) (state) (zip) (818) 886-6512 (phone)	

Evaluation Results

This method ( ) does (X) does not use multiple tests. If multiple tests are used, the results are based on _____ independent tests. The results apply only when ___ tests are performed and the estimated leak rates averaged.

This Leak Detection Method which declares tank to be leaking when the measured leak rate exceeds the threshold of -0.0446 gallons per hour, has a probability of false alarm [P_{FA}] of

0.8 % for tests conducted on tanks with a volume of 75,000 gallons or less when the threshold is set at 0.045 gal/h.

The corresponding probability of detection [P_D] of a 0.1 gallon per hour leak is 99.1 %, where the threshold is equal to 0.0817 gal/h.

The standard deviation of the test data results was 0.0176 gal/hr.

The smallest leak that can be detected with a probability of detection of 95% [MDL] is 0.0628 gal/hr.

The minimum water level (threshold) in the tank that the method can detect is N/A inches.

The minimum change in water level that can be detected by the method is N/A inches (provided that the water level is above the threshold).

Test Conditions During Evaluation

The evaluation testing was conducted in a nominal 50,000 gallon tank. The tank was constructed of (X) steel ( ) fiberglass (X) concrete ( ) other (describe)

The tank geometry was a horizontal cylinder that was 12 feet in diameter and 59 feet long.

The tests were conducted with the tank product level 95 % full.

The product used in the evaluation was Jet A .

The temperature differences between product added to fill the tank and product already in the tank were small (<1 degree F).

The system was operated as an automatic device. ( )Yes (X)No

Limitations on the Results

The performance estimates above are only valid when:

- The method has not been substantially changed.
- The vendor's instructions for installing and operating the Leak Detection Method are followed.
- The tank contains a product identified on the method description form.
- The tank is no larger than 75,000 gallons.

  The waiting time after adding any substantial amount of product to the tank is 5 hours 20 minutes.
- The total data collection time for the test is at least 5 hours 0 minutes.

- Other limitations specified by the vendor of determined during testing:

The best test results are obtained when testing at night and when activity around the tank is at a minimum.

Procedural Information

State the procedures used to compensate for the presence of a water table above the bottom of the tank.

If a water leak is present, into or out of the tank, the leak will be detected as an inflow.

State the procedures used to determine when the tank is stable.

Wait at least the specified stabilization period.

State the procedures used to account for fuels of different volatility.

No procedural changes are necessary.

Other Information

Summary of Test Procedure Modifications

No heating or cooling of the product delivered to the test tank.

Temperature Variations were achieved by: (describe briefly)

Transferring fuel between tanks. The temperature changes using this approach are minimal.

Other Modifications: (describe briefly)

> **Safety disclaimer: This test procedure only addresses the issue of the Leak Detection Method's ability to detect leaks. It does not test the equipment for safety hazards.**

Certification of Results

I certify that the Leak Detection Method was installed and operated according to the vendor's instructions and that the results presented on this form are those obtained during the evaluation.

H. Kendall Wilcox, Ph.D., President — (printed name)

Ken Wilcox Associates, Inc. — (organization performing evaluation)

______________ (signature)

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Description

Bulk Field-Constructed Tank
Leak Detection Method

This section describes briefly the important aspects of the bulk tank leak detection method. It is not intended to provide a thorough description of the principles behind the system or how the equipment works.

Method Name and Version

Portable Rapid Test (PRT) ver. 1.0

Product

> Product type

For what products can this Method be used? (check all applicable)

(X) gasoline

(X) diesel

(X) aviation fuel

(X) fuel oil #4

(X) solvents

(X) other (list) Any liquid.

> Product level

What product level is required to conduct a test?

(X) greater than 90% full

( ) greater than 50% full

( ) other (specify) Method is not sensitive to product level.

Does the Method measure inflow of water as well as loss of product (gallon per hour)?

(X) yes

( ) no

Does the Method detect the presence of water in the bottom of the tank?

( ) yes

(X) no

Principle of Operation

What technique is used to detect leaks in the tank system?

( ) directly measure the volume of product change

(X) changes in head pressure

( ) changes in buoyancy of a probe

( ) mechanical level measure (e.g., ruler, dipstick)

( ) changes in capacitance

( ) ultrasonic

( ) change in level of float (specify principle, e.g., capacitance, magnetostrictive, load cell, etc.) ____

( ) acoustical signal characteristics of a leak

( ) identification of a tracer chemical outside the tank system

( ) other (describe briefly) ____

Temperature Measurement

How many temperature sensors are used to measure the product temperature?

( ) Product temperature not measured

( ) One sensor

( ) Two sensors

( ) Three sensors

( ) Four sensors

( ) Five sensors

(X) Other (describe briefly) __None – system is mass based______________________

What type of temperature sensor is used?

(X) Product temperature not measured

( ) resistance temperature detector (RTD)

( ) bimetallic strip

( ) quartz crystal

( ) thermistor

( ) other (describe briefly) ____

If product temperature is not measured during a test, why not?

(X) the factor measured for change in level/volume is independent of temperature (e.g., mass)

(X) the factor measured for change in level/volume self-compensates for changes in temperature

(X) other (explain briefly) Reference tube in combination with differential pressure will compensate for temperature differences.

Data Acquisition

How are the test data acquired and recorded?

( ) manually

( ) by strip chart

(X) by computer

Procedure information

> Waiting times

What is the required waiting period between adding a large volume of product (i.e., a delivery) and the beginning of a test (e.g., filling from 50% to 90-95% capacity)?
_____Hours ______ Minutes

Additional Comments: ____

> Test duration

What is the required time for collecting data?

5 Hours 0 Minutes

Additional Comments: ____

What is the sampling frequency for the ~~level and temperature~~ pressure measurements?

( ) more than once per second

(X) at least once per minute

( ) every 1-15 minutes

( ) every 16-30 minutes

( ) every 31-60 minutes

( ) less than once per hour

( ) variable (explain) ____

> Use of multiple tests

Does the procedure use the average leak rate from more than one test in reaching a conclusion?

( ) Yes (How many tests? _________)

(X) No

Does the procedure base its conclusion on the agreement of k out of n tests?

( ) Yes (A leak is indicated if _________ (specify k) out of ___ (specify n) tests indicate a leak.)

(X) No

> Identifying and correcting for interfering factors

How does the Method determine the presence and level of the ground water above the bottom of the tank?

(X) level of ground water above bottom of the tank not determined

( ) observation well near tank

( ) information from USGS, etc.

( ) information from personnel on-site

( ) presence of water in the tank

( ) other (describe briefly) ____

Does the method measure inflow of water as well as loss of product?

(X) yes

( ) no

Additional Comments: ____

____

____

How does the Method correct for the interference due to the presence of ground water above the bottom of the tank?

( ) no action

(X) system tests for water incursion

( ) different product levels tested and leak rates compared

( ) other (describe briefly) ____

> Interpreting test results

How are level changes converted to volume changes (i.e., how is height-to-volume conversion factor determined)?

( ) actual level changes observed when known volume is added or removed (e.g., liquid metal bar)

(X) theoretical ratio calculated from tank geometry

(X) interpolation from tank manufacturer's chart

( ) other (describe briefly)

( ) not applicable; volume measured directly

How is the coefficient of thermal expansion (Ce) of the product determined?

( ) actual sample taken for each test and Ce determined from specific gravity

( ) value supplied by vendor of product

( ) average value for type of product

(X) other (describe briefly) Not required. Method is self-compensating for product temperature changes.

How is the leak rate (gallon per hour) calculated?

( ) average of subsets of all data collected

( ) difference between first and last data collected

(X) from data from last 5 hours of test period

(X) from data determined to be valid by statistical analysis

( ) other (describe) ____________________

What threshold value for product volume change (gallon per hour) is used to declare that a tank is leaking?

( ) 0.05 gal/hr	( ) 0.1 gal/hr	( ) 0.2 gal/hr
( ) 0.5 gal/hr	( ) 1.0 gal/hr	( ) 2.0 gal/hr

(X) Other -0.045 due to bias in test data

Additional Comments: ____________________

Under what conditions are test results considered inconclusive?

( ) ground water level above the bottom of the tank

( ) soil not sufficiently porous

(X) too much variability in the data (standard deviation beyond a given value)

( ) unexplained product volume increase

( ) other (describe briefly) ____

Exceptions

Are there any conditions under which a test should not be conducted?

( ) ground water level above the bottom of the tank

( ) large difference between ground temperature and delivered product temperature

( ) extremely high or low ambient temperature

( ) invalid for some products (specify) _________________________________

( ) other (describe briefly) ____

What are acceptable deviations from the standard testing protocol?

(X) lengthen the duration of test

( ) other (describe briefly) ____

( ) none

What elements of the test procedure are determined by personnel on-site?

(X) product level when test is conducted

(X) when to conduct test

(X) waiting period between filling tank and beginning test

(X) length of test (PRT-1 requires a minimum test time of 5 hours.)

( ) determination of "outlier" data that may be discarded

( ) other (describe briefly) ____

( ) none